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Electron Emission from Metal Surfaces*

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THE first known phenomena which today we would interpret as being caused in part by the emission of electricity from conducting surfaces were actually discovered some 200 years ago by Benjamin Franklin and others. These were phenomena associated with the loss of electrostatic charge by bodies placed in the vicinity of other bodies that were either hot or pointed. Today we know that thermionic emission or field emission is partly responsible for what were then somewhat puzzling observations.

However, the first real observation of electron emission as an isolated and interpretable effect occurred in 1883, when Edison observed the conductivity of a vacuum in which were placed a hot filament and an auxiliary electrode. Four years later Heinrich Hertz observed the effect of ultraviolet light on the sparking potential between two metallic electrodes, the first observation of the surface photoelectric effect.

It was O. W. Richardson in England and Hallwachs in Germany who, respectively, investigated these two effects and established the experimental foundation of thermionic and photoelectric emission. By 1920 it had been established that there were five important mechanisms by which electrons could be ejected from metal surfaces: (i) heat—the thermionic effect; (ii) light—the surface photoelectric effect; (iii) intense electric fields—field or "cold" emission; (iv) bombardment by ions or excited atoms; (v) bombardment by electrons—secondary emission. This discussion is confined largely to the first two of these phenomena, with only occasional reference to the others.

The photoelectric effect has always seemed to me to be one of the most fascinating experimental phenomena in physics. The reasons for this fascination are not hard to find. The interaction between radiation and electric charges is one of the most profound phenomena in physics, and even today its subtleties constitute one of the chief challenges to physical theory. The various types of photoelectric effect constitute one of the major aspects of this interaction; the experimental facts in this domain have for over 40 years provided a major stimulus to new advances in theory, and their explanation has been a conspicuous triumph of the more successful theories. At the same time, from the photoelectric and the thermionic effects have been developed practical applications of very extensive importance. This development has added a further incentive to attaining a more complete understanding of the phenomena and, incidentally, has brought the resources of some of the great industrial laboratories to bear on the problem.

Every student of physics is familiar with the way in which the elementary facts of the surface photoelectric effect in metals, as brought out in

* Address of the retiring President of the American Physical Society, January 30, 1948.

the work of Hallwachs, of Lenard and of Elster and Geitel at the end of the last century, were in direct contradiction to the then held classical theory of the action of electromagnetic waves on electrons. The Maxwell electromagnetic theory was in full accord with all phenomena then known in the field of optics; it had predicted the existence of radio waves and dealt successfully with problems of absorption and emission of radiations of radiofrequencies. In the high-frequency range, however, three baffling phenomena had refused to succumb to the blandishments of this almost perfect theory: (i) the energy distribution in the high-frequency end of the blackbody radiation spectrum, (ii) the puzzling regularities in the arrangement of spectral lines, and (iii) the photoelectric effect.

Planck found a clue to all three phenomena in his theory of blackbody radiation by introducing a discreteness in the process of emitting radiation, though retaining a continuity in the process of absorption. Planck attributed this discreteness not to the radiation but to a peculiar property of the radiating element.

It was still, therefore, a very bold step which Einstein took in 1905, when he assumed this discreteness to be inherent in the interaction between radiation and matter and deduced from this assumption his famous quantitative relation between the maximum energy of the photoelectrons and the frequency of the light. This relation was verified with great precision ten years later in the beautiful experiments of R. A. Millikan, and the cornerstone of the quantum theory was firmly laid.

The field of photoelectricity, however, having provided the cornerstone, seemed to have nothing further to add to the structure of the theory. It quietly sank into the background while physicists feverishly explored the field of atomic and molecular spectroscopy—a field in which the quantum theory scored one triumph after another, but in which it also met difficulties that gave rise to quantum mechanics.

But not all physicists were working in spectroscopy in those exciting years between 1918 and 1930. In 1922 I began graduate work at the University of Wisconsin with Professor C. E. Mendenhall. Mendenhall was a remarkable man, not so much because of any single great contribution he made to physics, but because of his keen insight, his versatility, and especially his ardent and intelligent interest in his students. These same characteristics were found in the other members of the department at that time: Max Mason, Warren Weaver, Leonard Ingersoll, J. R. Roebuck and others.

When I arrived at Madison, Mendenhall had one group of graduate students making accurate measurements of the blackbody radiation constant; other groups were working on spectroscopy, soft x-rays, ionization in gases, secondary electron emission, and so on. He suggested that I undertake a problem in photoelectricity. He still felt there were puzzling problems in this field to be cleared up. In fact, between 1922 and 1934 a larger and larger group at Madison investigated with great care the difficult problem of securing photoelectric data on really clean metallic surfaces. After Professor Mendenhall's death, work on this line was continued at Madison by H. B. Wahlin.

By 1922, interest in the photoelectric problem had shifted from the question of the nature of radiation to the question of the properties of metals and metal surfaces. Photoelectric data have, in fact, played a significant role in stimulating the development of the modern electron theory of solids and in providing experimental verification for certain of its conclusions. Conversely, the development of a quantum-mechanical theory of solids has greatly enhanced our understanding of photoelectric phenomena. Thus, just as the photoelectric effect provided a challenge and opportunity to the corpuscular quantum theory, it later provided a similar challenge to quantum wave mechanics, which responded by doing a far better job of clarifying photoelectric phenomena.

In the earliest studies of both photoelectric and thermionic effects the very great influence of the condition of the metal surface was observed. Ordinary mechanical and chemical cleaning of the surface produced marked changes in the electron emission. Further large changes were observed when the metal was heated in vacuum to drive off impurities and occluded gases. In fact, the changes due to residual traces of impurity were so great that no two observers could ever get the same results when studying a given

metal. Since the removal of impurities usually reduced the magnitude of the electron emission, it was seriously suggested that both the thermionic and photoelectric effects were entirely impurity effects and that really clean metals would show no electron emission at all!

Eventually, however, as high-vacuum technics developed, Langmuir showed that the thermionic characteristics of tungsten after thorough degassing approached stable values. The Wisconsin group found similarly characteristic photoelectric properties of platinum, silver, gold and other metals, and showed that the effect of impurities was merely to alter the surface work function. It was often necessary, however, to heat the surfaces at temperatures near the melting point for thousands of hours in the best attainable vacuum before the last traces of gas effects could be eliminated.

During this same period other investigators were giving great attention to introducing impurities to metal surfaces in order to enhance the electron emission for practical purposes in thermionic vacuum tubes and photocells. The enormous strides made in this direction and the tremendous practical results are well known. This work contributed greatly to our knowledge of surface potential barriers, but the contributions were mostly questions rather than answers, for it must be admitted that the practical success in obtaining efficient emitters has far outstripped our ability to understand in any quantitative way just what takes place in these complex surface layers.

But the development in the early twenties of technics of studying pure, and hence presumably simple, metal surfaces raised some ugly questions as to why we could not give a better theoretical description of their photoelectric properties. We might be satisfied to think that complex oxide layers on metals are difficult to treat theoretically. But one was repelled by the thought that no quantitative description could be developed for pure metals.

The classical electron theory of metals developed by Drude and Lorentz was, before 1927, the only base from which we could start. This theory achieved some successes, ran into many grave difficulties and was simply not fruitful in providing a basis for handling many problems. It

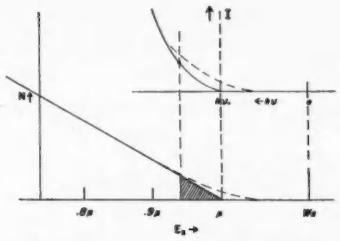

FIG. 1. *Lower curve:* upper end of Fermi curve for distribution of energy normal to surface, at 0°K (solid line) and at about 500°K (dashed curve). *Upper curve:* photo-current *versus* frequency, obtained by integrating the Fermi curve.

could not be said that the experimental facts of photoelectric emission were in direct contradiction to this theory. But it was equally true that the theory had cast but little light on the interpretation of these facts. Though the existence of a photoelectric threshold frequency and of an upper limit to the photoelectric energy spectrum were understandable, the theories could not predict the form of the yield or the energy distribution curves.

The Pauli-Sommerfeld free-electron theory of solids, introduced in 1927, and based on the Fermi-Dirac statistics, profoundly altered the picture. Even in its first simple form, it gave a much clearer picture of many electron emission phenomena.

In 1930–31, R. H. Fowler spent a year as visiting lecturer at Madison. There he undertook the task of applying this new theory of metals to the photoelectric problem. He deduced an approximate relation between photo-current, frequency and surface temperature that fitted beautifully the data already obtained by Mendenhall and his students.[1] Professor Mendenhall forwarded to me, then at Washington University, a copy of Fowler's paper, and it showed equally good agreement with a rather considerable amount of data which we had collected there. Within a few weeks, therefore, it was evident that Fowler's work had yielded an important success of the Pauli-Sommerfeld theory and had cleared up a host of puzzling relations in photoelectricity. I myself spent the next five years, in St. Louis and then in Rochester, examining the implications of the theory and testing it in various ways.

[1] R. H. Fowler, *Physical Rev.* **38**, 45 (1931).

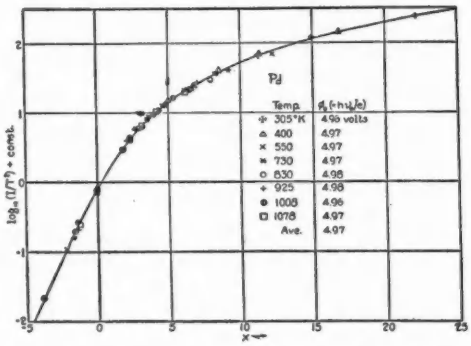

FIG. 2. Experimental test of Fowler theory (DuBridge and Roehr); $x \equiv h(\nu-\nu_0)/kT$.

The simple idea behind the Fowler theory is illustrated in Fig. 1. The lower curve shows the distribution in kinetic energy E_x normal to the surface for free electrons in a metal, as given by the Fermi-Dirac statistics. The "temperature tail" to this distribution is indicated by the dashed curve. If it were not for this tail, a light quantum of energy $h\nu_0 = W_a - \mu$ would just begin to cause the ejection of photoelectrons. For ν greater than ν_0 the number of electrons available for ejection is represented by the shaded area, and hence the photo-current I would rise in proportion to $(\nu-\nu_0)^2$. The temperature tail, however, has a marked effect even at room temperature, so that no sharp "threshold frequency" exists and there is no sharp upper limit to the energy of the ejected electron. Fowler formulated the equation for the actual form of the curve showing I as a function of ν; then by comparing the theoretical curve with experimental data the parameter $\nu_0[\equiv(W_a-\mu)/h]$ can be determined.

We still, unfortunately, use the term "threshold frequency" as a name for the quantity ν_0, even though we now know there is no frequency below which some electrons are not ejected at any temperature above 0°K. In fact, ν_0 is usually substantially higher than the frequency at which measurable currents are observed at room temperature. Nevertheless, the photoelectric work function $h\nu_0$ has a very definite meaning.

Now Fowler's theory was a very simple one. It did not involve any quantum mechanics and was, indeed, only a statistical calculation based on the Fermi-Dirac statistics. He assumed only that the probability of an electron's being excited and escaping was independent of the initial energy of the electron and of the frequency of the incident light. However, later calculations based on quantum mechanics, using the free-electron model and image-field surface potential barrier, showed this to be a good approximation if ν was not too much greater than ν_0. Within this limit the Fowler theory is astonishingly accurate. Figure 2 shows an experimental test of the theory.[2]

Although the approximations made in the theory limit its applicability to frequencies not too far from ν_0, actually no deviations are found over the normal range of frequencies used in experiments on the metals that have large work functions. However, for the alkali metals and others with thresholds in the visible spectrum, there are pronounced deviations at high frequencies. I shall refer to these later.

As a result of the success of the Fowler theory in predicting the form of the spectral distribution curves, I was led in 1932 to see whether the same statistical methods would yield expressions for the energy distribution of photoelectrons. Again surprisingly accurate results were obtained.[3] Figure 3 shows a test of this theory.[4] Though this

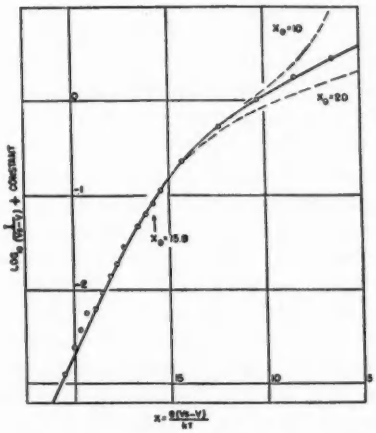

FIG. 3. Test of the theory of energy distribution of photoelectrons (Apker, Dickey and Taft).

[2] L. A. DuBridge and W. W. Roehr, *Physical Rev.* **39**, 99 (1932).

[3] L. A. DuBridge, *Physical Rev.* **43**, 727 (1933); see also *New theories of the photoelectric effect* (Hermann et Cie, Paris, 1934).

[4] Apker, Taft and Dickey, *Physical Rev.* **73**, 46 (1948).

curve appears to be similar to that of Fig. 2, it should be noted that in Fig. 3 we have a logarithmic graph of photo-current *versus* retarding potential V at a given frequency, whereas in Fig. 2 the saturation currents are plotted against incident frequency.

Though these results are quite satisfactory, one should not conclude that a complete and accurate theory of photoelectric emission had now been achieved. Far from it! As soon as we investigate metals where a wider range of frequencies can be used, troubles immediately arise. And, of course, they get really serious when composite surfaces are considered.

The basic problem in deducing a more complete quantum-mechanical theory may be stated fairly simply.[5] In any solid the possible energy states for electrons are grouped into bands (Fig. 4). For metals the uppermost band is only partly filled, or else the two uppermost bands overlap. The free-electron model for metals, therefore, ignores the lower bands, and this is tantamount to ignoring the periodic potential variation within the crystal lattice. One deals then with free electrons enclosed in a potential box. This is probably a good approximation for the alkali metals, at least. Interaction with radiation can then be calculated provided one knows the form of the surface potential barrier. Such calculations have been made by Mitchell, Schiff and Thomas, Makinson, and A. G. Hill.[6] For frequencies near the threshold the image barrier leads to the Fowler and DuBridge equations. But for frequencies corresponding to 1.5 ev or more above the threshold, the theory does not give results in agreement with experiment. This lack of agreement is shown in Figs. 5 and 6, taken from Hill's paper. Hill found that the energy distribution curves suggested a surface potential barrier with selective transmission for electrons of intermediate energy. This does not account, however, for the lack of agreement with the spectral distribution curves. This disagreement may be due to failure to take into account properly the optical constants of the surface, which, as Ives and his co-workers have shown experimentally, may have a profound influence.

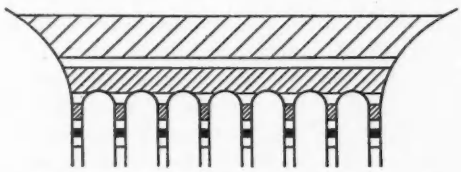

FIG. 4. Potential variation and electron energy states along a row of nuclei in a crystal; unshaded regions are forbidden.

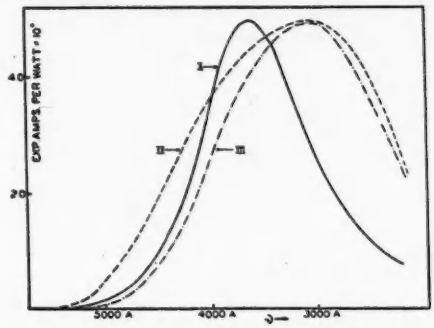

FIG. 5. Photo-current yield for Na (Hill): *I*, experimental; *II*, theoretical, image barrier; *III*, theoretical, selective barrier.

The fact that for any given surface the experimenter does not know the form of the potential barrier and does not usually measure the variation of the optical constants makes the problem of attaining a satisfactory theoretical calculation rather difficult!

In addition to these factors we know that the free-electron model of a metal is not a good approximation for the energy states in many cases, and the effects of the periodic lattice potential must be introduced. Tamm and Schubin[7] have shown that interaction between radiation and electrons in the lattice fields introduces an additional contribution to the photo-emission. They refer to this as the "volume effect" and show that it should have a threshold substantially higher than that for the surface effect. Cashman and Bassoe[8] have observed experimentally for barium surfaces the onset of this volume effect.

In summary, I think we can be confident then that the basic ideas and methods of quantum mechanics are capable of fully explaining photo-

[5] For a brief review of solid-state theory, see L. A. DuBridge, *Am. J. Physics* (*Am. Physics T.*) **7**, 357 (1939).
[6] For discussion and references, see A. G. Hill, *Physical Rev.* **53**, 184 (1938).
[7] Tamm and Schubin, *Zeits. f. Physik* **68**, 97 (1931).
[8] W. J. Cashman and E. Bassoe, *Physical Rev.* **55**, 63 (1939).

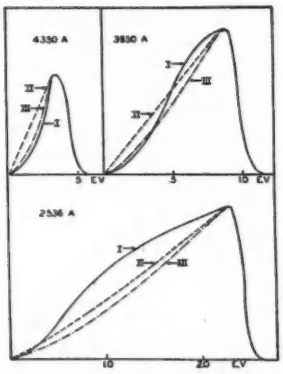

FIG. 6. Energy-distribution curves for Na (Hill): *I*, experimental; *II*, image field; *III*, square barrier.

electric data and that the failure to achieve precise agreement can be attributed (i) to our inadequate knowledge of surface properties, and (ii) to the difficulties of calculation in cases where the free-electron model is inaccurate.

I wish now to turn briefly to the subject of thermionic emission. Since this is essentially an evaporation phenomenon its temperature dependence can be deduced purely from thermodynamics, as was done by Richardson. Two assumptions must be made: (i) the value of the specific heat of the electrons in the metal, and (ii) the temperature dependence of the heat of evaporation or the work function. The original Richardson equation, $I=aT^{\frac{1}{2}}e^{-b/T}$, assumed the electron's specific heat to have the classical value $\frac{3}{2}R$. The Dushman equation, $I=AT^{2}e^{-b_0/T}$, assumed the specific heat to be zero. Both assumed that the work function was independent of temperature, though a temperature variation is easily included.

A *statistical* theory of thermionic emission, based on the Sommerfeld theory of metals, and assuming a constant work function, yields the Dushman equation in which the quantity A turns out to be a universal constant, equal to 120 amp/cm² deg². Values of this quantity deduced from the usual Richardson graph, however, vary widely, especially for contaminated surfaces. Many clean surfaces exhibit values of about 60 amp/cm² deg². This was a puzzle until it was realized that if the surface work function varies even slightly with temperature the value of A is drastically affected. Deviations from the theoretical value of 120 are usually attributed to this effect. Values less than 120 could also be ascribed to a low transmission coefficient of the surface barrier. This, however, can probably account for very small deviation only. The relation[9] between the slope and intercept of graphs of thermionic emission is shown in Fig. 7.

The relation between the photoelectric and thermionic work functions of a metal has been studied rather extensively, and experiment shows, as theory predicts, that the two are approximately equal. The experimental values of A, however, suggest that in a typical case a difference of about 1 percent should be observed between room-temperature photoelectric values and the high-temperature thermionic values. This difference, however, is just about at the limit of experimental accuracy and has not been fully established. Becker and Brattain[9] gave a careful analysis of this whole problem in 1934, and their[9] paper should be required reading for anyone working in the field. Before it appeared there was considerable inaccurate thinking on the problem of the relations between work functions and their temperature dependence; and, as these authors correctly point out, the papers of DuBridge and his co-workers were not entirely free from confusion on this point!

I can mention only briefly the electron-emission characteristics of composite surfaces. This field is full of complex problems, greatly lacking in adequate theoretical interpretation, but nevertheless of great importance practically. The enormous advance in the development of photo-cells, for example, is due to success in finding, by largely empirical trials, composite surfaces of very low work function, sensitive well into the infra-red. But we have only the crudest ideas as to why these particular surfaces exhibit such a behavior.

The simplest composite surface and the one first investigated by Langmuir is thoriated tungsten. In this case, temperature treatments have been evolved that leave the tungsten surface covered to any desired degree with a monatomic layer of thorium atoms. It is not difficult to see how these electropositive atoms would exist essentially as ions on the surface and, with their

[9] J. R. Becker and W. H. Brattain, *Physical Rev.* **45**, 694 (1934).

image charges, constitute a double layer which would reduce the work required for an electron to escape. Similar effects occur for other electropositive atoms, such as caesium, on tungsten or similar metals. Still larger reductions in work function occur when a thin oxide layer is formed on the metal before the caesium is deposited, and a wide variety of surfaces can be formed by varying the underlying metal and the thickness of the oxide and the caesium layers. But the details of how the surface barrier is altered by such composite layers are still not fully understood.

One phenomenon that complicates the behavior of complex surfaces is that they are usually nonuniform, with patches of low work function interspersed with patches of higher work function. Even clean surfaces of polycrystalline metals may show patch effects, since different crystal faces of a metal are known to show different work functions. One observable effect of the patch structure is that local electric fields due to contact potentials between patches prevent the escape of some electrons unless high external accelerating fields are applied. In other words, the electron currents do not saturate. This effect, indeed, may be used to estimate the nature and size of the patches, as has been shown by Becker and his co-workers.

Of course, electron currents from pure surfaces do not really saturate either. Even under conditions of negligible space charge a slow rise in emission with voltage is always observed, and at very high fields electron emission is observed for surfaces that are neither illuminated nor heated. At low fields the rise in current is called the *Schottky effect* and is due to a lowering of the surface potential barrier. This effect has, indeed, been used to explore the shape of the barrier, and more work of this type might well be profitable in removing some of our ignorance about surface fields. At very high fields the barrier is not only lowered but is rendered so thin that unexcited free electrons may "leak" through it. This is the same type of effect that gives rise to radioactive emission of alpha-particles, and those two effects, alpha-decay and field emission, always seemed to me to be among the most spectacular of the confirmations of quantum mechanics.

I will only mention in conclusion the puzzle of secondary emission. In the photoelectric effect, an incident quantum confers its whole energy on a free electron in the metal, which then has a certain probability of escape. Actually, only one electron emerges for each 1000 or so quanta absorbed. Presumably, most of the quanta are wasted on electrons that end up with an energy too low to escape, or that are not moving toward the surface.

However, an *electron* impinging from outside with a relatively high speed may divide its energy among many internal electrons, several of which may escape. The number escaping per primary—the secondary-emission ratio—varies roughly between 0.5 and 1.5 for clean surfaces but rises to 6 or even 10 for certain composite surfaces. Also it varies with the primary energy, usually reaching a maximum for incident electrons of energies 600 to 1000 ev. In some cases, there is a rough parallelism between this ratio and the value of the surface work function, suggesting again that many electrons are excited to energies too low to escape—but the parallelism frequently is nonexistent. Most puzzling of all is the observation of Pomerantz[10] made during the war, that for ordinary alkaline earth-oxide thermionic cathodes the secondary-emission ratio rises sharply *with temperature*, reaching values of the order of 100 at a few hundred degrees Centigrade. This,

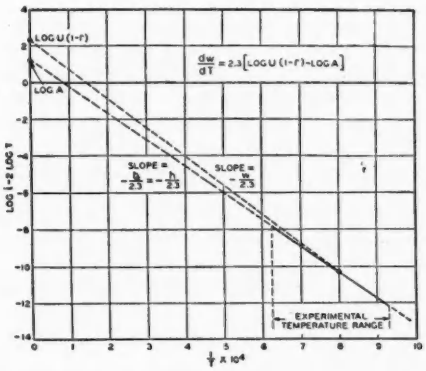
LOG U (1-r)
LOG A
$\frac{dw}{dT} = 2.3[\text{LOG U (1-r)} - \text{LOG A}]$
SLOPE = $-\frac{b}{2.3} = -\frac{h}{2.3}$
SLOPE = $-\frac{w}{2.3}$
EXPERIMENTAL TEMPERATURE RANGE
LOG I - LOG T
$\frac{1}{T} \times 10^4$

FIG. 7. Slope and intercept relations for thermionic data (Becker and Brattain). If $b/2.3$ is the slope and $\log A$ the intercept of an experimental Richardson graph, then A will equal $U(\equiv 120$ amp/cm^{2}deg$^2)$ only if the work function W is independent of T; $h \equiv W - T\,dw/dt$.

[10] M. Pomerantz, *Physical Rev.* **70**, 33 (1946).

incidentally, is an important reason for some of the spectacular characteristics of cavity magnetrons. The average energy of the secondaries falls sharply as their number rises, so the principle of conservation of energy does not fail. But at that point our theoretical understanding of this remarkable phenomenon seems to stop.

This is an inadequate and rather superficial review of the field. I hope, however, that possibly there are one or two experimental physicists who are not building big cyclotrons who might be inspired to turn attention to this problem. And possibly some theoretical physicist might also re-examine this field while he is waiting for some one to get a good idea about how to treat the problem of nuclear forces.

Recommendations of the AAAS Cooperative Committee

The following paragraphs summarize the recommendations of the Cooperative Committee on the Teaching of Science and Mathematics of the American Association for the Advancement of Science, as given in Appendix 2, volume 4, of the Steelman report, Manpower for Research. The recommendations are based on the results of a survey, a factual summary of which, without interpretation or conclusion, appears on pages 241–243 of this issue.—EDITORS.

The Committee came to the conclusion, as evidenced in the summary, that teaching of the physical sciences and mathematics is at present based primarily on tradition and the use of textbooks and courses but not really on a basic development of concepts in a form that can be understood by a student. It therefore recommended establishing a National Commission on the Teaching of Science and Mathematics which should investigate this problem in detail.

Recognizing the necessity of early identification of science talent, the Committee recommended that special procedures should be set up to test for science talent, and that full subsistence scholarships should be established on a local, state and federal basis to educate American youth to the limit of its ability.

On the level of undergraduate and graduate teaching, the Committee recognized the great difficulty due to overloading of the university and college curriculum, and it recommended a rigorous screening to avoid the overcrowding of colleges, particularly the science departments, with students who are not competent to study these subjects. It also recommended a rigorous screening in the graduate schools, particularly of Ph.D. candidates; it recommended requirements for the Master's degree that would permit definite decision between terminating a student's academic career with the Master's degree in science, or encouraging him to go on for a Ph.D. degree.

Exchange of scientists between academic and industrial fields and between colleges and large universities was recommended, and a detailed program for the improvement of instruction was discussed.

The Committee fully realized that the task of improving science instruction at the secondary level could not be neglected. If graduation requirements in the secondary schools are to include one year of physical science, a large number of additional teachers must be trained and counseling service will have to be provided for in-service teacher training.

On the other hand, during the survey for the President's Scientific Research Board, it became clear that a continuation of the study of science education at the college and university level was equally important. The Committee, therefore, approached the parent societies to authorize expansion of its activities to include a study of science teaching in institutions of higher learning.

The Cooperative Committee on the Teaching of Science and Mathematics of the AAAS will therefore continue to study: (i) problems of teacher training and science education at the secondary level; (ii) science education of the specialist in colleges and universities; and (iii) science in general education.

The Structure of Cubic Crystals as Revealed by X-Rays

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ALTHOUGH the structures of cubic crystals have been well established by x-ray diffraction methods, they are still ambiguously described in some of the widely used chemistry and physics textbooks.[1–5] Of the three types of cubic crystals—(i) simple cubic, (ii) body-centered cubic, and (iii) face-centered cubic—the units of structure attributed by these books to the last two, which are most common are not those of actual cubic crystals. The unit of structure is taken as a unit cube rather than a unit cell. Not only does such a unit not fit the observed physical facts associated with these structures, but the introduction of this concept confuses the student at the very outset of his study of crystallography. The instructor who adopts this concept will generally find it difficult to present material on structure of cubic crystals, especially if his field of specialization is not x-rays or crystallography. The objectives of this paper are (i) to point out the difficulties now experienced in presenting structures of cubic crystals, (ii) to show how actual cubic crystals are characterized, and (iii) to describe structures of cubic crystals that are derived from observed diffraction data.

Concept of the Unit Cell

A crystal consists of atoms or ions arranged in a pattern that repeats itself periodically in three dimensions. A crystal unit cell is the smallest possible subdivision that has the properties of the visible macrocrystal and which, by repetition in all directions with parallel orientation, yields the physical crystal. As shown in Fig. 1, the unit cell is characterized by six lattice parameters: three unit distances a_0, b_0, c_0 along the X, Y, Z axes, respectively, and three interaxial angles α, β, γ.

The characteristics of the unit cell of a cubic crystal are that $a_0=b_0=c_0$ and $\alpha=\beta=\gamma=90°$. The interplanar distance d of parallel planes in the unit cell of a cubic crystal (see Fig. 2 and Appendix I) is the length of the normal drawn from the origin—which lies in one of the planes of the series—to the next parallel plane of the series. Its value is given by the equation

$$d_{(hkl)}=a_0/(h^2+k^2+l^2)^{\frac{1}{2}}, \qquad (1)$$

in which h, k, l are the Miller indices of the set of planes, that is, integers proportional to the reciprocals of the intercepts of the planes along the directions of a_0, b_0 and c_0. Thus, the interplanar distance of different sets of parallel planes of cubic crystals [Table I(A)] may be calculated by substituting values of h, k, l in Eq. (1). The planes here referred to are those that contain lattice points of the crystal.

It should be emphasized that a_0 for any substance having one type of cubic cell will seldom if ever be equal to a_0 for a substance having another type of cubic cell. Even two elements that crystallize in the same cubic structure do not have the same values of a_0.

A corresponding list of values for the same interplanar distances, taken from the textbooks already mentioned, is given in Table I(B); here a_0' is used for the length of an edge of the unit cube.

The values of $d_{(110)}$ for body-centered cubic and $d_{(111)}$ for face-centered cubic crystals of Table I(B) are double the corresponding values of Table I(A). This difference arises from the facts that these values are based on the structure of Fig. 3(B), in which a_0' is the length of the side of the unit cube and is equal to one-half of a_0, the side of the unit cell. The spacing $d'_{(100)}$ is actually $d_{(200)}$, $d'_{(110)}$ is $d_{(220)}$, and $d'_{(111)}$ is $d_{(222)}$. The volume of the unit cube, consequently, is only one-eighth of the volume of the actual unit cell of edge a_0. A description of the structure of a body-centered or face-centered cubic crystal

[1] Getman and Daniels, *Outline of physical chemistry* (Wiley, ed. 6, 1937).
[2] Physics Staff of University of Pittsburgh, *Atomic physics* (Wiley, ed. 2, 1937).
[3] G. E. M. Jauncey, *Modern physics* (Van Nostrand, ed. 3, 1948).
[4] A. H. Compton, *X-rays and electrons* (Van Nostrand, 1928).
[5] J. A. Crowther, *Ions, electrons and ionizing radiation* (Longmans, Green, ed. 4, 1924).

TABLE I(*A*). Interplanar distance *d* of certain sets of planes of cubic crystals, using unit cell.

Type of crystal	Planes (100)	(110)	(111)
Simple cubic	a_0	$1/\sqrt{2}\cdot a_0$	$1/\sqrt{3}\cdot a_0$
Body-centered cubic	a_0	$1/\sqrt{2}\cdot a_0$	$1/\sqrt{3}\cdot a_0$
Face-centered cubic	a_0	$1/\sqrt{2}\cdot a_0$	$1/\sqrt{3}\cdot a_0$

TABLE I(*B*). Interplanar distance *d* of certain sets of planes of cubic crystals, using unit cube.

Type of crystal	Planes (100)	(110)	(111)
Simple cubic	a_0	$1/\sqrt{2}\cdot a_0$	$1/\sqrt{3}\cdot a_0$
Body-centered cubic	a_0'	$2/\sqrt{2}\cdot a_0'$	$1/\sqrt{3}\cdot a_0'$
Face-centered cubic	a_0'	$1/\sqrt{2}\cdot a_0'$	$2/\sqrt{3}\cdot a_0'$

based on such a unit leads to ambiguities and mistakes.

Structures of Cubic Crystals

The volume of the unit cell of a cubic crystal is a_0^3. The number N of atoms or molecules associated with each type of unit cell and their coordinates (u, v, w) in the unit cell are given in Table II. This number may be verified from Fig. 3(*A*). In the unit cell of a simple cube the corners of the cube coincide with the centers of the corner atoms and only one-eighth of each of these atoms is within the cell. Therefore, $N=8\times\frac{1}{8}=1$. Similarly, for a body-centered cube, $N=(8\times\frac{1}{8})+1=2$; and for a face-centered cube, $N=(8\times\frac{1}{8})+(6\times\frac{1}{2})=4$, since one-half of each of the atoms at the center of the face is contained within the cell. The number of atoms associated with each cell must necessarily be a whole number.

From the size and shape of the unit cell and the number of atoms contained, the density of the crystal may be computed (Table III); it is equal to the product of the mass per atom and the number of atoms per unit cell, divided by the volume of the unit cell. Conversely, when the volume of the unit cell, the atomic weight and the density of the substance are known, the number of atoms per unit cell can be computed.

As has been shown, each type of unit cell has a definite number of atoms or molecules associated with it, and in a crystalline substance the atoms occupy definite positions in the unit cell. These positions and the type of atoms occupying them may be determined from an x-ray diffraction pattern formed by the crystal. The size and the shape of the unit cell, and the positions of atoms in it determine the position of the diffracted beams in the pattern. The types of atoms in various positions in the unit cell determine the intensities of the diffracted beams. When the dimensions of the unit cell, the number and the types of atoms in it and their scattering powers for x-rays are known, the atoms may be assigned arbitrary positions in the cell. As a check, the intensities of the beams diffracted from various crystal planes may be calculated (see Appendix II) and, if the calculated intensities agree with the observed intensities, the positions assigned to each type of atom in the unit cell must be their actual positions.

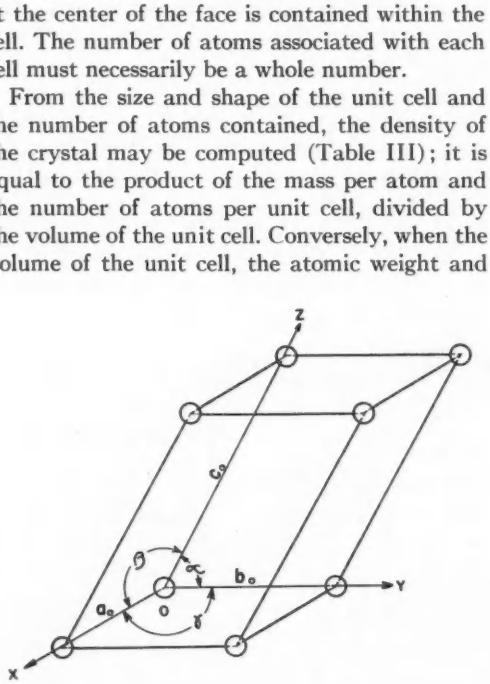

FIG. 1. The unit cell.

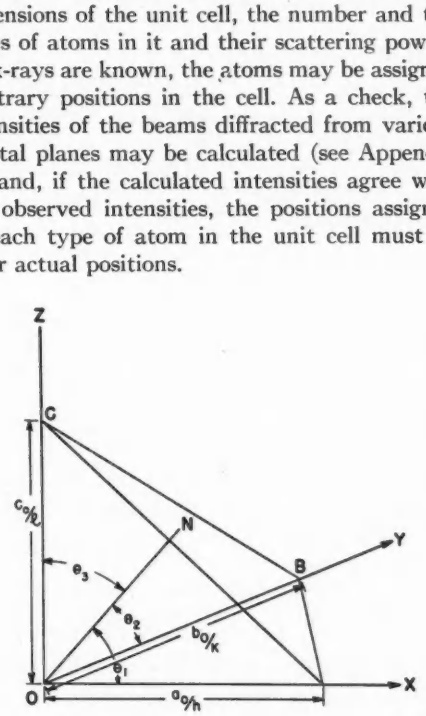

FIG. 2. The intercepts of crystal plane *hkl* (first of the type from the origin).

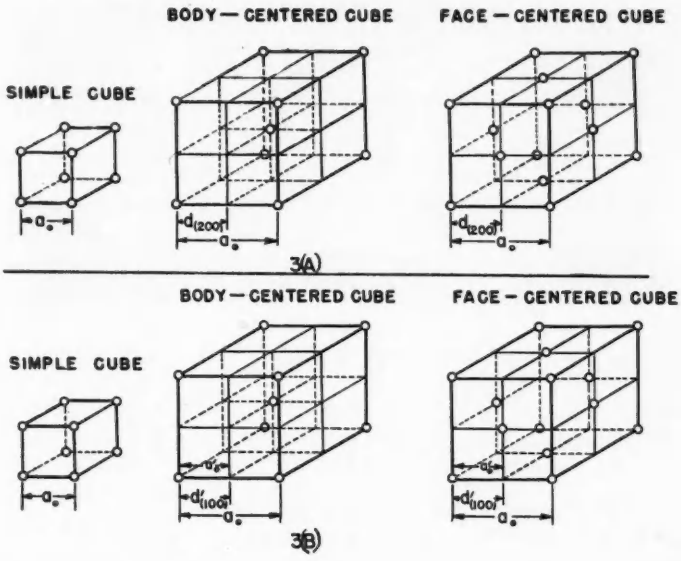

Fig. 3. The unit cells of cubic crystals.

As an illustration, Fig. 4 shows x-ray diffraction patterns of body-centered cubic tungsten and face-centered cubic copper made by the powder method. The diffraction data that may be derived from them—such as the glancing angle θ, interplanar spacing d, Miller indices h, k, l, and the calculated and the observed relative intensities I of the diffraction lines—are given for tungsten in Table IV and for copper in Table V. In these tables f, F, M and $L.P.$ are atomic scattering factor, structure factor, multiplicity factor and Lorentz-polarization factor, respectively, as explained in Appendix II. The agreement between the calculated and the observed intensities is quite satisfactory when corrections due to back-scattering and the separation of K_α doublets at large diffracting angles are taken into account. The positions assigned to atoms in each unit cell, therefore, are their actual positions.

The Miller indices h, k, l of the diffracting planes in the body-centered cubic structure are not identical with those in the face-centered cubic. From the indices obtained here and from the structure determinations of other cubic crystals, it is well known that the possible diffractions from the three types of cubic unit cells are those given in Table VI. It can be easily verified that they are described by the following rules.

Type of cell	Condition on h, k, l
Simple cube	No restrictions
Body-centered cube	$h+k+l$ even
Face-centered cube	$h+k$, $h+l$, $k+l$ even; i.e., h, k, l all odd or all even

Thus, a rational structure of a cubic crystal must be characterized by the number of atoms and their positions in each type of unit cell, and

TABLE II. Number N of atoms and their coordinates in the unit cell.

Type of crystal	N	Coordinates
Simple cubic	1	0, 0, 0
Body-centered cubic	2	0, 0, 0; $\frac{1}{2}, \frac{1}{2}, \frac{1}{2}$
Face-centered cubic	4	0, 0, 0; $\frac{1}{2}, \frac{1}{2}, 0$; $\frac{1}{2}, 0, \frac{1}{2}$; $0, \frac{1}{2}, \frac{1}{2}$

TABLE III. Atomic and crystal characteristics of tungsten and copper.

Metal crystal type	Tungsten body-centered cubic	Copper face-centered cubic
Atomic weight	183.92	63.57
Mass per atom (10^{-24} g)	305.38	105.55
N	2	4
a_0 (10^{-8} cm)	3.1585	3.608
Volume of unit cell (10^{-24} cm^3)	31.514	46.97
Density (g/cm^3):		
Calculated	19.36	8.99
Measured	19.3	8.94

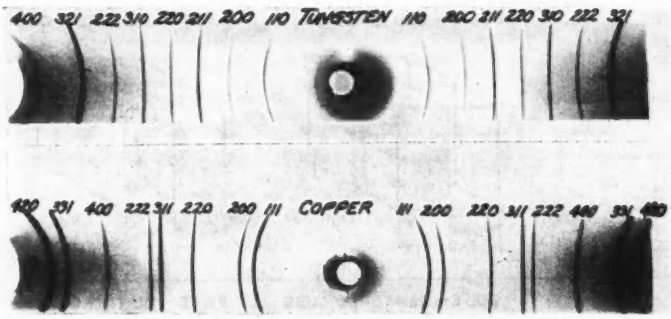

FIG. 4. X-ray diffraction patterns of tungsten and copper; $\lambda = 1.539$A; diameter of camera, 57.3 mm.

by the sequence of Miller indices characteristic of such a cell.

Ambiguities in the Presentation of the Crystal Structure of KCl

Potassium chloride, like sodium chloride, crystallizes in a cubic structure (Fig. 5). Some authors[2–6] appear to reason that since KCl is an ionic crystal, and since the numbers of electrons in the K^+ and Cl^- ions are equal—that is, the orbital electrons are 18 in each case—the x-ray scattering powers of the two ions should be identical and the structure of KCl, therefore, should be of the simple cubic type. In support of this contention, x-ray diffraction patterns of KCl, similar to the one given in Fig. 6, have been presented.[3,6] It is inferred that the gap following the sixth line in the pattern is characteristic of the simple cubic crystal, because in such a structure the values of $h^2+k^2+l^2$ for successive reflections are 1, 2, 3, 4, 5, 6, 8, $\cdots$. The reflection corresponding to $h^2+k^2+l^2=7$ is missing, as there are no three integers the sum of whose squares is 7 and, since $d_{hkl}=a_0/(h^2+k^2+l^2)^{\frac{1}{2}}$, such a reflection is not possible. Others assume that KCl is a close approximation to a simple cubic crystal, and use it as a teaching device to introduce crystal structures to beginning or intermediate students. It seems to work well to visualize a simple cubic structure having half of its corners filled with K^+ ions and the other half with Cl^- ions and the unit of structure a unit cube with the cube edge equal to the spacing between K^+ and Cl^- ions along any of the crystal axes.

As will be shown, however, the structure of KCl is not one of the simple cubic type. The foregoing reasoning is not adequate to establish it. The coherent scattering power of an atom or ion for x-rays depends not only on its atomic or ionic number but also on the glancing angle θ of the incident beam. The electrons in the various parts of an atom do not scatter in phase. Also, as shown in Fig. 7, the scattering factors of the K^+ ion are larger than those of the Cl^- ion for all values of $\sin\theta/\lambda$ except zero. This variation is dependent largely on the fact that in the K^+ ion the electrons are closer to the nucleus on the average than in the Cl^- ion. Furthermore, the structure of a crystalline substance is determined not on the basis of the scattering powers of the atoms alone, but also according to their

TABLE IV. X-ray diffraction data and calculated relative intensities for tungsten. Powder pattern; $\lambda = 1.539$A.

No. of line	θ (deg)	$\sin\theta$	d(A)	hkl	$\sin\theta/\lambda$	f	F^2	M	L.P.	I/1000 (calc.)	I* (obs.)
1	20.35	0.3475	2.23	110	0.226	58.4	13,640	12	6.94	1136	V.S.
2	29.25	0.4886	1.58	200	0.318	51.6	10,652	6	3.05	195	W
3	36.60	0.5962	1.29	211	0.388	46.9	8,800	24	1.90	401	M
4	43.45	0.6877	1.12	220	0.447	43.5	7,568	12	1.45	132	W
5	50.15	0.7677	1.00	310	0.499	40.5	6,560	24	1.37	216	W+
6	57.20	0.8406	0.913	222	0.546	39.0	6,084	8	1.52	74	V.W.
7	65.40	0.9092	0.848	321	0.591	37.5	5,616	48	2.07	558	S
8	68.60	0.9311	0.828	400	0.605	35.6	5,068	6	2.43	74	V.W.

* V=Very, S=Strong, M=Medium, W=Weak.

[6] W. P. Davey, *Study of crystal structure and its applications* (McGraw-Hill, ed. 1, 1934).

TABLE V. X-ray diffraction data and calculated relative intensities for copper. Powder pattern; $\lambda = 1.539$A.

No. of line	θ (deg)	$\sin\theta$	d(A)	hkl	$\sin\theta/\lambda$	f	F^2	M	L.P.	I/1000 (calc.)	I (obs.)
1	22.00	0.3746	2.08	111	0.243	20.0	6400	8	5.87	301	V.S.
2	25.35	0.4282	1.81	200	0.278	18.8	5655	6	4.20	143	S
3	37.15	0.6039	1.28	220	0.392	15.7	3944	12	1.82	86	M
4	45.00	0.7071	1.09	311	0.458	13.9	3091	24	1.41	105	M
5	47.75	0.7402	1.04	222	0.481	13.5	2916	8	1.39	32	W
6	58.40	0.8517	0.905	400	0.554	12.3	2421	6	1.58	23	V.W.
7	63.15	0.8922	0.830	331	0.580	11.8	2228	24	1.88	101	M
8	72.05	0.9513	0.809	420	0.618	11.2	2007	24	2.96	143	S

distribution in the unit cell. The assumption that KCl is a close approximation to a simple cubic structure is an unfortunate one because it not only portrays a faulty structure, but introduces a concept of a unit cube rather than a unit cell, a concept that is not followed in crystal structure determinations.

The lattice of KCl, as shown in Fig. 5, is built up of two interpenetrating face-centered cubic structures, one for the K^+ ion and the other for the Cl^- ion. That is similar to that of NaCl may be seen from the comparative data given in Tables VII to IX. The side of the unit cell a_0, the volume of the unit cell and the number of molecules or atoms per unit cell for both KCl and NaCl are given in Table VII. The positions of the atoms in the unit cell and the expressions for structure factor for a structure of the sodium chloride type are given in Appendix II. The diffraction data for KCl are given in Table VIII and for NaCl in Table IX. These data were obtained from x-ray diffraction patterns of KCl and NaCl made by the usual Debye-Scherrer-Hull method (Fig. 6).

In Table X are given for comparison the Miller indices and the calculated and observed relative intensities of diffraction lines that appear in the patterns of both KCl and NaCl. In column 4 are included the calculated relative intensities of lines that appear in the pattern of NaCl but are absent in the usual x-ray diffraction pattern of KCl. The absence of one of these lines creates a gap following the sixth line in the pattern and, as already mentioned, this gap has been used to characterize the KCl structure.

The relative intensities of the lines with odd Miller indices, such as 111, 311, 331, 333–511, 531, 533 and so forth, in structures of the sodium chloride type are, in general, weak. This is because the intensity of a diffraction line for a powdered specimen (Appendix II) is proportional to the square of the structure factor and the structure factor is proportional to the difference in the atomic scattering factors of two types of atoms when h, k, l are all odd. For K^+ and Cl^- ions, as shown in Fig. 7, these differences are very small. Consequently, the relative intensities of these lines in the KCl pattern are very weak. The lines are too weak to be observed in the usual x-ray diffraction pattern, but they are not zero, as must follow if the KCl structure is one of simple cubic type.

TABLE VI. Miller indices of all possible planes that would give diffractions from the three types of cubic unit cell of orders up to 422.

Simple cube	Body-centered cube	Face-centered cube
100	—	—
110	110	—
111	—	111
200	200	200
210	—	—
211	211	—
220	220	220
300	—	—
221	—	—
310	310	—
311	—	311
222	222	222
320	—	—
321	321	—
400	400	400
410	—	—
411	411	—
331	—	331
420	420	420
421	—	—
332	332	—
422	422	422

The difference between neutron scattering cross sections and hence the scattering lengths[7] of K^+ and Cl^- ions is greater than the difference in the x-ray atomic or ionic scattering factors of the two ions. The relative values of structure factors and the intensities of the lines with odd Miller indices are greater than the intensities of corresponding reflections obtained with x-rays. Whereas the lines with odd Miller indices in the x-ray diffraction pattern of KCl are too weak to be observed, they are observed[8] in the

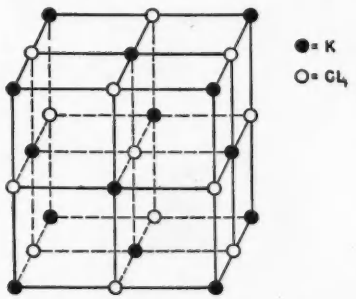

FIG. 5. Potassium chloride lattice. *Note:* The upper right corner should read: ● = Cl, ○ = K.

[7] E. Fermi and L. Marshall, *Physical Rev.* 71, 666 (1947).
[8] Shull and Wollan, *Bull. Am. Soc. X-Ray and Electron Diffraction*, summer meeting (1947).

TABLE VII. Molecular and crystal characteristics of KCl and NaCl.

Crystal	KCl	NaCl
Molecular weight	74.55	58.55
Mass per molecule (10^{-24} g)	122.79	96.28
a_0(10^{-8} cm)	6.280	5.628
Volume of unit cell (10^{-24} cm^3)	247.7	178.2
Density (g/cm^3)	1.984	2.165
Mass per unit cell (10^{-24} g)	491.4	385.8
No. of molecules per unit cell	4.0	4.0
No. of atoms per unit cell	8	8

TABLE VIII. X-ray diffraction data and calculated relative intensities for potassium chloride. Powder pattern; $\lambda = 1.539$A.

No. of line	θ (deg)	$\sin\theta$	d(A)	hkl	$\sin\theta/\lambda$	f_{K^+}	f_{Cl^-}	F^2	M	L.P.	I/1000 (calc.)	I (obs.)
1	14.30	0.2470	3.12	200	0.161	14.6	12.7	11925	6	14.97	1071	V.S.
2	20.35	.3477	2.21	220	.227	12.5	10.8	8686	12	7.06	736	S
3	25.15	.4050	1.81	222	.277	11.3	9.7	7056	8	4.41	249	M
4	29.40	.4909	1.57	400	.319	10.3	9.0	5960	6	3.01	108	W
5	33.05	.5453	1.41	420	.255	9.7	8.6	5358	24	2.34	301	M+
6	36.90	.6004	1.28	422	.390	8.9	8.2	4679	24	1.91	214	M
7	43.65	.6902	1.11	440	.449	8.2	7.6	3994	12	1.46	66.1	W-
8	46.95	.7310	1.05	442	.475	8.0	7.4	3794	24	1.38	126	W+
9	50.50	.7716	0.992	620	.502	7.7	7.2	3552	24	1.37	117	W
10	54.15	.8105	.948	622	.528	7.5	7.1	3411	24	1.43	117	W
11	57.65	.8448	.909	444	.550	7.4	6.9	3272	8	1.55	40.6	V.W.
12	61.65	.8801	.873	640	.572	7.2	6.7	3091	24	1.77	131	W+
13	66.00	.9135	.841	642	.594	7.1	6.6	3003	24	2.14	154	M

TABLE IX. X-ray diffraction data and calculated relative intensities for sodium chloride. Powder pattern; $\lambda = 1.539$A.

No. of line	θ (deg)	$\sin\theta$	d(A)	hkl	$\sin\theta/\lambda f_{Na^+} f_{Cl^-}$	F^2	M	L.P.	I/1000 (calc.)	I (obs.)
1	13.70	0.2368	3.25	111	0.154	8.8	13.1	260	8	16.38	34.1	W
2	15.89	.2738	2.81	200	.178	8.5	12.2	6856	6	11.93	490.1	V.S.
3	22.75	.3867	1.99	220	.251	7.4	10.4	5069	12	5.40	329.0	S
4	26.91	.4526	1.70	311	.294	6.8	9.5	117	24	3.68	10.3	V.W.
5	28.25	.4733	1.63	222	.308	6.6	9.2	4743	8	3.31	78.2	M
6	33.15	.5468	1.41	400	.355	5.9	8.6	3364	6	2.32	46.8	W
7	37.00	.6018	1.29	331	.391	5.4	8.2	125	24	1.86	5.6	V.W.
8	37.60	.6101	1.26	420	.396	5.3	8.1	2873	24	1.81	125.0	M+
9	41.95	.6685	1.15	422	.434	4.8	7.8	2540	24	1.52	92.7	M
10	45.70	.7157	1.08	{333 {511	.465	4.5	7.5	64	{8 {24	1.40	{0.7 {2.2	V.W.
11	50.60	.7727	0.995	440	.502	4.0	7.2	2007	12	1.37	33.0	W
12	54.00	.8090	.951	531	.526	3.8	7.0	164	48	1.42	11.2	V.W.
13	54.95	.8186	.939	442	.532	3.7	6.9	1798	24	1.45	62.6	M
14	59.65	.8630	.891	620	.561	3.4	6.8	1664	24	1.65	65.9	M
15	63.65	.8961	.858	533	.582	3.2	6.6	185	24	1.92	8.5	V.W.

TABLE X. Miller indices, calculated and observed relative intensities of reflections in patterns of NaCl and KCl.

hkl	NaCl I/1000(calc.)	NaCl I(obs.)	KCl I/1000(calc.)	KCl I(obs.)
111	34.1	W	7.03	O
200	490	V.S.	1071	V.S.
220	329	S	736	S
311	10.3	V.W.	5.03	O
222	78.2	M	249	M
400	46.8	W	108	W
331	5.6	V.W.	1.04	O
420	125	M+	301	M+
422	92.7	M	214	M
{333 {511	{0.7 {2.2	V.W.	{0.12 {0.36	O
440	33.0	W	66.1	W
531	11.2	V.W.	0.36	O
442	62.6	M	126	W+
620	65.9	M	117	W
533	8.5	V.W.	0.14	O

neutron diffraction pattern, thus confirming that KCl is a face-centered cubic structure and that the gap following the sixth line in the x-ray diffraction pattern is no criterion for a determination of its structure.

The writer's sincere thanks are due Miss Gretta L. Scott in obtaining the x-ray diffraction patterns, Dr. J. A. Berger for help with the figures, and Mrs Elizabeth Robertson for secretarial assistance.

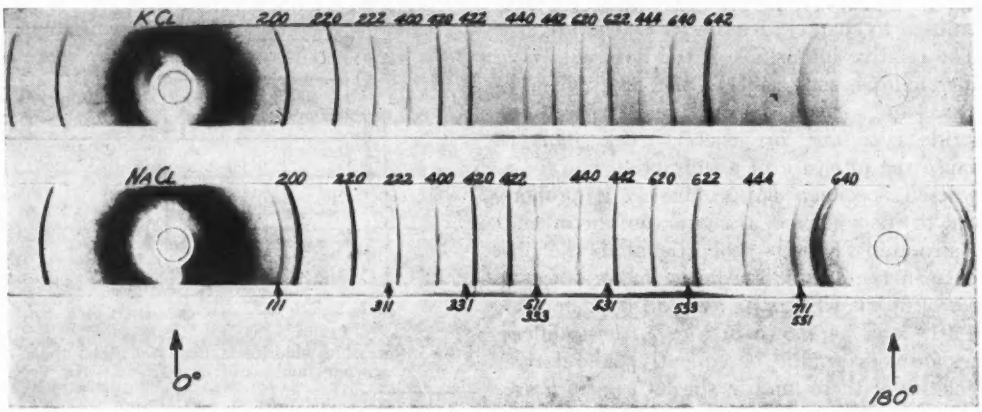

FIG. 6. X-ray diffraction patterns of KCl and NaCl; $\lambda = 1.539$A; diameter of camera, 114.6 mm.

TABLE XI. Structure factor expressions for different types of cubic structure.

Type of structure	No. of atoms per unit cell	Coordinates u, v, w	Expression for F
Simple cubic	1	0, 0, 0	$F=f$
Body-centered cubic	2	0, 0, 0; ½, ½, ½	$F=f[1+\cos\pi(h+k+l)]$
Face-centered cubic	4	0, 0, 0; ½, ½, 0; ½, 0, ½; 0, ½, ½	$F=f[1+\cos\pi(h+k)+\cos\pi(h+l)+\cos\pi(k+l)]$
Sodium chloride	8 (4 molecules)	Cl: 0, 0, 0; ½, ½, 0; ½, 0, ½; 0, ½, ½ Na: ½, ½, ½; 0, 0, ½; 0, ½, 0; ½, 0, 0	$F^2=16(f_{Cl}\pm f_{Na})^2$, according as h, k, l are all even or all odd

TABLE XII. Miller indices of planes in cubic unit cells and corresponding multiplicity factors.

hkl	Multiplicity factor	hkl	Multiplicity factor
100	6	321	48
110	12	400	6
111	8	410	24
200	6	411	24
210	24	331	24
211	24	420	24
220	12	421	48
300	6	332	24
221	24	422	24
310	24		
311	24		
222	8		
320	24		

Appendix I. Calculation of Interplanar Spacings of Cubic Crystals.

Let OA, OB and OC (Fig. 2) be the intercepts of plane ABC on the X, Y and Z axes, respectively, and ON the normal from the origin to the plane. Let θ_1, θ_2 and θ_3 be the direction angles that ON makes with OA, OB and OC, respectively. Then $OA=a_0/h$, $OB=b_0/k$, $OC=c_0/l$, and $ON=d$. Also, $ON/OA=\cos\theta_1$, $ON/OB=\cos\theta_2$, $ON/OC=\cos\theta_3$. Since $\cos^2\theta_1+\cos^2\theta_2+\cos^2\theta_3=1$, it follows that

$$\left(\frac{d}{a_0/h}\right)^2+\left(\frac{d}{b_0/k}\right)^2+\left(\frac{d}{c_0/l}\right)^2=1.$$

For a cubic crystal, $a_0=b_0=c_0$; hence,

$$(d_{hkl})^2=a_0^2/(h^2+k^2+l^2),$$

or

$$d_{hkl}=a_0/(h^2+k^2+l^2)^{\frac{1}{2}}.$$

Appendix II. Calculation of Intensities of X-Ray Diffraction Lines.

The intensities given in Tables IV, V, VIII, IX and X were calculated from the relation $I\propto F^2M(1+\cos^2 2\theta)/(\sin 2\theta\sin\theta)$, where F is the structure factor, M the multiplicity factor, and $(1+\cos^2 2\theta)/(\sin 2\theta\sin\theta)$ the Lorentz-polarization factor. The square of the structure factor F is obtained from the expression $F^2=\Sigma(f\cos\phi)^2+\Sigma(f\sin\phi)^2$, where f is the atomic scattering factor and $\phi[=2\pi(hu+kv+lw)]$ is the phase angle. The expressions for the structure factor F of different types of cubic crystals are given in Table XI.

The multiplicity factor M is equal to the number of permutations of the Miller indices of a diffracting plane. The factors M for the most important diffractions from the three types of cubic unit cells are given in Table XII.

The factor $\frac{1}{2}(1+\cos^2 2\theta)$ is the polarization factor and $1/(\sin 2\theta\sin\theta)$ the Lorentz factor for powder diffraction patterns. The combined factor $(1+\cos^2 2\theta)/(\sin 2\theta\sin\theta)$ is called the Lorentz-polarization factor $L.P.$ The factor ½ is omitted since the expression for I includes only those terms that vary with each diffraction line.

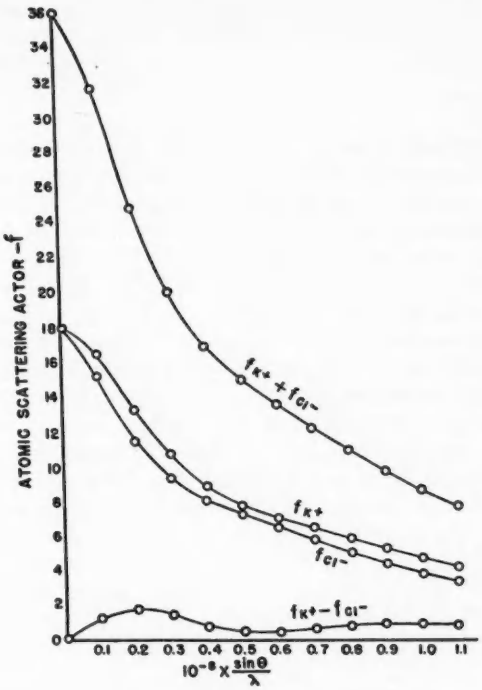

FIG. 7. X-ray scattering curves for KCl.

Boners

Since $v=at$, then $a=v/t$; and since $s=\frac{1}{2}at^2$, then $a=2s/t^2$. Therefore, $v/t=2s/t^2$, or $v=2s/t$. But $s/t=v$. So $v=2v$, or $1=2$!

[*Contributed by J. Stanley Johnson, The University of North Carolina.*]

Electromagnetic Waves in Spherical or Solid-Angular Regions

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IN this note we propose to consider the electromagnetic field in regions having spherical symmetry or in general conical regions. We are interested in expressing the field vectors **E** and **H** in terms of a suitable potential which obeys the wave equation and in classifying the solutions in terms of fundamental modes or eigenwaves. The investigator is faced with this question in many antenna and horn problems, in problems of the diffraction around spherical objects, and, recently, in quantum electrodynamics.

The literature on this point of classical radiation theory is not inconsiderable. The treatment given in the textbooks is quite lengthy, because of the fact that spherical coordinates r, θ, φ and usually also spherical vector components have been employed. The resulting formulas are complicated and clumsy enough to make the emergence of a wave equation appear as a lucky accident.

In his work on diffraction around spheres Debye[1] was able to express the r-, θ- and φ-components of the field vectors in terms of a scalar function in two ways: in one the radial component of **E** is zero, while in the other that of **H** vanishes. Sommerfeld[2] pointed out that Debye's potentials were to a certain extent equivalent to radially directed Hertzian vectors; but in each of the two cases he had to operate with a further scalar function as well, so that his formulas appear to offer but little in the way of simplification. More recently Hansen[3] has given an interesting integration theory of Maxwell's equations, of which a clear account is given by Stratton.[4] The final equations are the same as those of the previously mentioned authors and, while perhaps some insight has been won into the reasons for some of the potentials used, no real gain as to simplicity and ease of classroom presentation has been achieved.

A paper by Heitler[5] contains a classification of the eigenwaves of the Maxwell field, using a mixture of spherical polar coordinates and complex linear combinations of cartesian vector components. No Hertzian vector, only Lorentz potentials, are employed. While the approach of Heitler to the problem comes closest to our own as presented below, the resulting formulas, owing to the specialized coordinates employed, are quite complicated and the initial hypothesis as to the form of the expressions used for the potentials seems justified only by the result.

The developments offered herein are of course not new so far as results go; they are claimed however, to be simpler than the standard methods previously quoted. They have been presented repeatedly during the past several years in the author's course on the partial differential equation of physics. The following points distinguish the present method from others and bring out the simplicity and terseness of the formulas.

(i) Instead of spherical coordinates Cartesian coordinates are used throughout; where r occurs, it serves merely as an abbreviation for $(x^2+y^2+z^2)^{\frac{1}{2}}$.

(ii) Curvilinear vector components like E_θ, H_φ, and so forth are avoided; only Cartesian components are used.

(iii) Hybrid devices, such as $x+iy$, $E_x \pm iE_y$, which only cause the z-axis to play a preferred role are not employed.

(iv) Instead of spherical surface harmonics, Legendre polynomials, and so forth, perfectly general solid harmonics[6] are used.

(v) The field vectors **E** and **H** are derived from Hertzian vectors by means of formulas which, because of (i) and (ii), differ in no way from the

[1] P. Debye, *Ann. d. Physik* **25**, 377 (1908).
[2] P. Frank and R. von Mises, *Die Differential- und Integralgleichungen der Mechanik und Physik*, vol. 2, sec. V; A. Sommerfeld, *Electromagnetic oscillations* (Rosenberg, New York, 1943), p. 871.
[3] W. W. Hansen, *Physical Rev.* **47**, 139 (1935); *J. Appl. Physics* **7**, 460 (1936); **8**, 282 (1937).
[4] J. A. Stratton, *Electromagnetic theory* (McGraw-Hill, 1941), chap. VII, esp. pp. 414 ff.
[5] W. Heitler, *Proc. Cambr. Phil. Soc.* **32**, 112 (1936).
[6] A solid harmonic of degree l, to be denoted by $\mathfrak{H}^{(l)}$, is defined here as a homogeneous function of x, y, z of degree l which is a solution of Laplace's equation; l may or may not be integer.

usual form; the Hertzian vector used here is not radially directed.

(vi) The index notation is used consistently. This means that in place of x, y, z, from now on x_i will be written, where i, as well as any other subscript which occurs can assume the values 1, 2 or 3. Also an index occurring twice in any one term is automatically summed.[7] The use of this notation is made possible by the absence of any preferred direction in space. It is held here that the decomposition of the field into the principal modes is an invariant property of the differential equations and therefore should appear independent of coordinates or preferred directions.

A few more conventions as to notation will be set forth here. All field quantities are supposed to have a time factor $\exp(+i\omega t)$, which will be omitted. When a function, say f, is differentiated with respect to a coordinate x_i, it will be written $f_{,i}$. For instance, the Laplacian of f will be written $f_{,\alpha\alpha}$.

As is well known, two types of solution of Maxwell's equations result. In one type, called H wave or TE wave,[8] the radial component of **E** is absent; in the other type, E wave or TH wave, the radial component of **H** is absent.

1. Derivation of the Field Vectors from a Hertzian Vector

Maxwell's equations, written by means of the index notation, are

$$\left.\begin{array}{ll} ikH_j=\epsilon_{j\alpha\beta}E_{\alpha,\beta}, & ikE_j=-\epsilon_{j\alpha\beta}H_{\alpha,\beta}, \\ E_{\alpha,\alpha}=0, & H_{\alpha,\alpha}=0, \end{array}\right\} \quad (1)$$

where k is the wave number ω/c; ϵ_{ijk} is equal to ± 1 according as i, j, k constitute an even or odd permutation of 1, 2, 3, and is zero otherwise.

TH Wave.—**E** and **H** are derived in the usual fashion from the Hertzian vector **Z**;

$$E_j=Z_{\alpha,j\alpha}+k^2Z_j; \quad H_j=-ik\epsilon_{j\alpha\beta}Z_{\alpha,\beta}. \quad (2)$$

Substitution of these relations into Eqs. (1) shows[9] that each component of **Z** has to fulfill the wave equation

$$Z_{i,\rho\rho}+k^2Z_i=0. \quad (3)$$

So far, only familiar formulas have been written down. Now the following hypothesis as to the form of Z_i is made:

$$Z_i=f^{(l-1)}\mathfrak{C}^l_{,i}, \quad (4)$$

where $f^{(l-1)}$ is a function of the radius vector r only, and $\mathfrak{C}$ denotes a harmonic function of degree l, which therefore satisfies the two equations

$$\mathfrak{C}^l_{,\rho\rho}=0; \quad x_\rho\mathfrak{C}^l_{,\rho}=l\mathfrak{C}^l. \quad (5)$$

When l is an integer such a function is called a solid harmonic. Clearly, $\mathfrak{C}^l_{,i}$ is a function of type $\mathfrak{C}^{l-1}$, hence the superscript $l-1$ on f. Substitution of Eq. (4) in Eq. (3), together with Eqs. (5), shows that the directional dependence inherent in $\mathfrak{C}$ can be separated off and only a second-order differential equation for f remains. This equation will be written

$$r^2\ddot{f}+(2l+1)\dot{f}+k^2f=0, \quad (6)$$

where $\dot{f}$ stands for $r^{-1}df/dr$. Inspection shows this to be the differential equation of the familiar spherical Bessel functions.[10] To gain further information as to the choice of $\mathfrak{C}^l$ it is necessary to calculate the field vectors by substituting Eq. (4) in Eqs. (2). This gives for the magnetic field intensity

$$H_i=-ik\dot{f}\epsilon_{i\alpha\beta}\mathfrak{C}_{,\alpha}x_\beta. \quad (7)$$

This vector has no radial component, for

$$x_\rho H_\rho=0, \quad (7')$$

which accounts for the name "TH wave." The electric field intensity becomes

$$E_i=l\dot{f}\mathfrak{C}x_i+l\dot{f}\mathfrak{C}_{,i}+k^2f\mathfrak{C}_{,i}. \quad (8)$$

The radial component of **E** is, of course, not zero, as is seen from the equation

$$x_\rho E_\rho=-l(l+1)\dot{f}\mathfrak{C}, \quad (8')$$

which can be derived with the help of Eq. (6).

TE Wave.—The formulas which take the place of Eqs. (2) to (8) will be recorded without proof. The field vectors are derived from the Hertzian

[7] An example is the square of the radius vector: $r^2=x_\alpha x_\alpha$

[8] This notation is that employed in J. C. Slater, *Microwave transmission* (McGraw-Hill, 1942).

[9] Using the identity $\epsilon_{rij}\epsilon_{rkl}=\delta_{ik}\delta_{jl}-\delta_{il}\delta_{jk}$.

[10] We are not at present concerned with the selection of particular solutions of Eq. (6) nor with questions of normalization. Certain of the following formulas can be simplified by writing $f^{(l)}$ for $\dot{f}^{(l-1)}$.

vector by means of the equations

$$E_j = ik\epsilon_{j\alpha\beta}Z_{\alpha,\beta}; \quad H_j = Z_{\alpha,j\alpha} + k^2 Z_j. \qquad (2_1)$$

The same type of Hertzian vector as before is employed and nothing is changed from Eqs. (3) to (6). The electric vector is

$$E_j = ik\dot{f}\epsilon_{j\alpha\beta}\mathfrak{K}_{,\alpha}x_\beta, \qquad (7_1)$$

with

$$x_\rho E_\rho = 0; \qquad (7_1')$$

while the magnetic vector is

$$H_i = l\dot{f}\mathfrak{K}x_i + l\dot{f}\mathfrak{K}_{,i} + k^2 f\mathfrak{K}_{,i}, \qquad (8_1)$$

and

$$x_\rho H_\rho = -l(l+1)\dot{f}\mathfrak{K}. \qquad (8_1')$$

2. The Influence of Boundary Conditions on $\mathfrak{K}$

We are not here concerned with radial boundary conditions, which will either restrict the allowed values of k to a discrete set or specialize the f functions to represent incoming or outgoing waves. The boundaries whose influence we wish to discuss are general conical boundaries, such as arise from the motion of a ray whose point of issuance, the origin, is kept fixed. First of all, it is clear that when the whole unrestricted solid angular region of 4π steradians is available, the boundary condition just spoken of becomes a condition of finiteness and one-valuedness, with the results that all positive integral values of l are possible and that $2l+1$ linearly independent harmonics exist for each l. These are the familiar multipole solutions. If the angular region is restricted to be a definite cone of perfectly conducting material, the determination of the l values becomes an eigenvalue problem depending essentially upon the boundary conditions to be imposed on the harmonics. It is these boundary conditions that are to be investigated here. Let the equation of the bounding cone be

$$h(x, y, z) = 0, \qquad (9)$$

where h is a homogeneous function (algebraic or transcendental) of the coordinates. Its normal is determined by a unit vector

$$\nu_i = (h_{,\rho}h_{,\rho})^{-\frac{1}{2}}h_{,i}. \qquad (10)$$

Perpendicular to $\vec{\nu}$ are the radius vector $\mathbf{r}$ and an equatorial vector, which will be denoted by $\vec{\mu}$, with components

$$\mu_i = r^{-1}\epsilon_{i\alpha\beta}x_\alpha\nu_\beta. \qquad (11)$$

The boundary conditions require that the r- and μ-components of $\mathbf{E}$ and the ν-component of $\mathbf{H}$ vanish on the cone. We take up TH waves first and see from Eq. (8′) that for the vanishing of the r-component of $\mathbf{E}$ it is necessary that $\mathfrak{K}$ vanish on the cone. Will this also cause the μ-component,

$$\mu_\rho E_\rho = r^{-1}\epsilon_{\rho\alpha\beta}x_\alpha\nu_\beta(l\dot{f} + k^2 f)\mathfrak{K}_{,\rho}, \qquad (12)$$

to vanish? In order that $\mathfrak{K}$ vanish on the cone, $\mathfrak{K}$ has to be a factor of the cone equation; that is, h has to be of the form

$$h = \mathfrak{K}G, \qquad (9')$$

where G is some other homogeneous function of x, y, z. This causes Eq. (12) to become

$$\begin{aligned}\mu_\rho E_\rho &= \cdots \epsilon_{\rho\alpha\beta}x_\alpha(\mathfrak{K}_{,\beta}G + \mathfrak{K}G_{,\beta})\mathfrak{K}_{,\rho} \\ &= \cdots \epsilon_{\rho\alpha\beta}x_\alpha G_{,\beta}\mathfrak{K}_{,\rho}\cdot\mathfrak{K},\end{aligned}$$

in which only terms essential to the present proof have been written down. The first term in the bracket vanishes because of the antisymmetry of ϵ. So here, too, if $\mathfrak{K}$ vanishes, the μ-component vanishes. Now take the ν-component of $\mathbf{H}$, namely

$$\nu_\rho H_\rho = \cdots \epsilon_{\rho\alpha\beta}\mathfrak{K}_{,\alpha}x_\beta(\mathfrak{K}_{,\rho}G + \mathfrak{K}G_{,\rho});$$

by the same token a vanishing $\mathfrak{K}$ will make this zero. Summarizing, we have for TH waves:

$$E_{\tan} = 0, \quad H_{\text{norm}} = 0, \quad \text{if } \mathfrak{K} = 0.$$

Turning to TE waves, we recall that the radial component of $\mathbf{E}$ vanishes everywhere. The equatorial component is

$$\mu_\rho E_\rho = r^{-1}\epsilon_{\rho\alpha\beta}x_\alpha\nu_\beta E_\rho = \cdots (x_\lambda\mathfrak{K}_{,\lambda}\nu_\alpha x_\alpha - r^2\nu_\lambda\mathfrak{K}_{,\lambda}).$$

The first term vanishes and the second contains

$$\nu_\lambda\mathfrak{K}_{,\lambda} = \partial\mathfrak{K}/\partial\nu,$$

the normal derivative whose vanishing therefore ensures the vanishing of the μ-component of $\mathbf{E}$. Finally, the normal component of $\mathbf{H}$ is, by virtue of Eq. (8_1),

$$\nu_\rho H_\rho = \cdots [l\dot{f}\mathfrak{K}x_\rho\nu_\rho + (l\dot{f} + k^2 f)\nu_\rho\mathfrak{K}_{,\rho}],$$

so the same reasoning applies as before. Thus for

TE waves,

$$E_{\tan}=0, \quad H_{\text{norm}}=0, \quad \text{if } \partial\mathfrak{C}/\partial\nu=0.$$

Thus it is seen that for the two wave modes either $\mathfrak{C}$ or its normal derivative must vanish on the boundary of the cone. It is therefore necessary to solve what are known as the "first" and "second" boundary-value problems for the domain in question. With existing mathematical methods this is possible only for a circular cone, for conal spaces bounded by meridian planes and circular cones, for elliptical cones, for conal spaces bounded by pieces of elliptic cones and for certain regions created by three planes intersecting in one point. For other regions numerical methods must be employed.

New Frontiers*

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ALL who have given the Richtmyer Memorial Lectures have shared the feeling that they were dealing with matters that would be close to the heart of Floyd Karker Richtmyer (1881–1939). When one considers the range of subjects treated in these lectures and the variety of points of view represented, this means that Richtmyer was a many-sided man who touched physics on all of its principal frontiers. He was not one of the founders of the American Physical Society, but he had a part in the expansion of the interests of physicists that resulted in the formation of other societies concerned with physics. He was also one of the first to realize the dangers inherent in the multiplication of societies and the need for unification in the American Institute of Physics.

I recall vividly our experiences at the Cleveland meetings in 1930 when the processes of division and of unification were going on at the same time —the former through the organization of the American Association of Physics Teachers and the latter through the initial steps in the organization of the American Institute of Physics. The question was immediately raised as to whether the new Association was sufficiently a part of physics to be recognized as a founder society of the Institute of Physics. It was feared that the American Association of Physics Teachers would be devoted to pedagogy in a narrow sense. This was by no means the intent of the founders of the Association, for it was conceived as an organization of physicists for the promotion of a more effective development of one aspect of our activity as professional physicists.

At Cleveland I happened to be elected the first president of the new Association, and I realized that its position in American physics must be settled both quickly and rightly. The character of the AAPT would be determined by the type of men who became its first members and who sponsored its development as members of the first executive committee. There had to be a liberal representation of men who, although deeply interested in the teaching of physics, were recognized as leaders in research. Consequently, before the close of the Cleveland meetings I presented this point of view to Richtmyer and Karl Compton, and they met the challenge and accepted places on the first executive committee. I vividly recall how A. W. Hull also met the challenge and gave the address, in May 1931, that constituted our first program. He helped set the pattern for the Association by treating physics teaching as an important activity of physics, an activity having significance even for the physicist primarily concerned with pure research. About a year later the American Association of Physics Teachers was recognized as a founder society of the Institute of Physics, and ten years later one of the Associations, nominees on the Governing Board, Paul Klopsteg, was elected Chairman of the Institute.

The success of the unification expressed through, and brought about by, the Institute is evidenced by the fact that the members of the Governing

* The seventh Richtmyer Memorial Lecture of the American Association of Physics Teachers, delivered at the 17th annual meeting, Chicago, Illinois, December 30, 1947.

Board, while nominated in groups by individual societies, do not serve as *representatives* of the societies. In fact, they are usually members of two or three of the member societies.

Nevertheless, as one who has been close to the development of the Institute during most of the 17 years of its life, I can say, without fear of contradiction, that those who have led in the unification process and have worked hardest for a broad concept of the place of physics in contemporary civilization have been almost without exception men who have been active in the affairs of the Association. This is not surprising, for those are objectives that the AAPT has furthered from the first.

Richtmyer was notable for his breadth of interest. He was a member of several of the founder societies of the Institute—not because he was a "joiner," but because of his ability to work effectively in many fields. He was a pioneer in extending the boundaries of physics along many of the frontiers to which this lecture will refer.

Just as many teachers of physics cannot lecture comfortably unless standing in front of a blackboard, chalk in hand, so many of us, when confronted with the preparation of an essay or a lecture, are better able to organize our thoughts through some sort of picture or diagram. We like to use analogies and, being spatially minded, we like the kind that can be visualized in three dimensions.

So, in trying to organize my thinking about the frontiers that physicists now face and have faced through the years, I have pictured physics as comprising a volume in some sort of unconventional space. This may be thought of narrowly as a subject-matter space, but I prefer to think of it more broadly as a sort of functional space in which the coordinates are related to all of the activities in which physicists engage. This volume, which is the domain of physicists, continually changes in magnitude and shape as internal and external forces bring about advancement of its frontiers in various directions and at varying rates.

For present purposes we may imagine the volume as having started as an idealized cube whose expansion in space may occur on any one of six faces or frontiers which we will think of as representing: *pure research; applied physics and technology; exchange of technical knowledge; education*, including general dissemination of knowledge; *professional activities;* and a sixth which, for lack of a better name, might be called *social participation*. We should not let ourselves be hampered by the fact that a cube has six faces; we can, in fact, think of the domain as having long since expanded into a bulgy, ill-defined volume, with progress occurring on many old and new frontiers.

Obviously, a complete examination of the past and present extensions of the physicist's activity domain on any one of these frontiers is a major project and one that could not be dealt with in a reasonable length of time. I propose to do little more than mention developments in pure and applied research and to concentrate more on developments and frontiers in the other directions.

Pure Research in the United States

While the development of pure research in the United States is relatively recent, it has been great enough to give this country the leadership in the world. The present boundaries of this region of pure research are so extensive that few men are able to know more than a limited section of it. I have no intention of trying to examine these frontiers, but it may be profitable to consider briefly past developments and to cite some of the factors that have aided the expansive process.

Expansion of graduate study.—Because the doctor's degree stresses research, there is some correlation between the rate of granting such degrees in physics and the extent of research in physics. The first earned Ph.D. degree in physics in this country was conferred by Yale in 1861. This degree was apparently based on two years' work, and the emphasis on pure research probably was not great. It was, in fact, not until the opening of The Johns Hopkins University in 1876 that the fruitful association of graduate work and research became clearly established. Until then only six Ph.D. degrees in physics had been conferred—all by Yale. By 1890 the total number had risen to 30; by 1895 the cumulative total was only 50. In the five-year period 1908–1912, 135 were conferred. In a five-year period immediately preceding World War II, 1936–1940, 766 men and women received Ph.D. degrees in physics, or

nearly six times as many as during the five-year period 28 years earlier.

The American Physical Society.—The founding in 1899 of the American Physical Society, with 59 members, was a recognition of the growing interest in pure research. Its subsequent growth to its present membership of more than 5500 parallels the expansion of the research activities of physicists.

Not long ago, among my papers, I came across the program of the first annual meeting of the American Physical Society that I ever attended. It was held at Minneapolis in December 1910. The program was presented on a four-page folder and listed 43 papers. At the Washington meeting last spring sessions ran concurrently in six places and there were 192 papers. In 1910 there was one society of physicists; now there are five, each with formidable programs. The American Physical Society and its official journal, the *Physical Review*, not only serve to illustrate by their growth the expansion of American research in physics but also have contributed enormously to that expansion by providing a focal point for research activities and a means of disseminating the results.

Single-hearted devotion marked the opening up of the widening frontiers of research in the United States. It is understandable, but no less unfortunate, that so many early leaders in American physics felt that the proper expansion of physics along the frontiers of research excluded as a suitable activity of professional physicists developments along those other frontiers to which we will presently turn our attention and from which fruitful results are also derived.

Postdoctoral fellowships.—A feature to which many ascribe great importance in fostering research has been the establishment of the postdoctoral fellowships administered by the National Research Council. Begun after the last war, they have acquired a significance which suggests that careful attention should be given to the possibilities residing in proposals now under discussion for increased subsidization of science and science education.

A number of serious studies, including that embodied in the recent report of the President's Scientific Research Board, indicate that, because of a shortage of trained manpower, the rate of expansion of our research frontier promises to be less than is desirable in the national interest. It is apparent that the amount and kind of governmental activity in science and in education will exert powerful forces on our expansion. It is obvious that this situation is of vital concern to the entire domain of physics; it not only deserves the most careful and critical attention from all of us, but also requires that we assume actual leadership in helping direct these forces to accomplish desirable objectives.

Within the research portion of the total volume of physics activity have arisen forces or pressures that have modified its expansion along some of the other coordinates; conversely, the pure research portion has been affected by pressures within other parts of the volume. The close relationship between graduate education and research is one example of this interdependence of the various parts of the volume. Another is the effect of the war-induced expansion of applied research and technology in temporarily slowing down expansion in pure research by the forced orientation of physicists' activities in the direction of technology.

Applied Physics and Technology

The expansion of physics in the realm of applied physics and technology is nothing new. The existence in the past of a tendency for prominences or bulges to form in the applied-research—and to a lesser extent in the pure-research—portions of the volume is familiar to all of us. These bulges result from rapid extension in a particular direction and have had, in the past, a tendency to become wholly or partially disconnected from the main volume, forming new islands only lightly connected with the parent mass.

Examples will occur to everyone. In my own experience, I recall that when I first taught electrical measurements to junior students of electrical engineering in 1910, one of the co-authors of the textbooks which they were studying in electrical engineering was William S. Franklin. He is remembered as a forceful figure at meetings of the Physical Society, and he was posthumously awarded the first Oersted medal.[1] In 1910 electrical engineering was still in the process of separating from physics and was not very cordially accepted by the traditional engineering branches. Since then we have seen the development of acoustical engineering and illuminating engineering and the quick and eager capture by others of great areas of applied physics in communications and electronics.

[1] *Am. J. Physics* (*Am. Physics T.*) **5**, 31 (1937).

This sloughing off by physics of these and other branches of applied physics is a natural process, and a healthy one if it is not carried too far. The basic science should expect to have numerous progeny. But too many engineers and physicists forget that much of engineering is logically, if not historically, an extension of the domain of physics. Until the last war the public understood this hardly at all. Here chemistry has been more fortunate, for the word *chemical* combines well in phrases like *chemical engineering*, *chemical education*, and the like. The trouble that the word *physical* causes is illustrated by the normal connotation of the phrase *physical education*. So unfortunate has the name *physics* been that there was serious talk of attempting to change the name of our science until World War II made physics almost a household word. The idea of a change of name is not so shocking when we recall how recently our science was "natural philosophy."

This war tore down the boundaries that had been built up between physics and engineering, and in the process brought out strikingly the different and sometimes antagonistic points of view of those who think narrowly of the relationship which should exist between fundamental and applied science.

Partly through the influence of the American Institute of Physics and partly because it just had to be, the frontiers of physics have been pushed far into the laboratories of hundreds of industrial concerns. It is to be hoped that the closer association of physicists and engineers in industry, and more liberal mental attitudes on the part of both physicists and engineers, will result in the discovery of wide areas where physicists and engineers can cooperate in pushing forward the frontiers of applied science. I am reminded of the closing remarks of Karl Darrow in the third Richtmyer Memorial Lecture when he said:

> If anyone is paralyzed by the recurrence of the feeling that there is only one system of the world and somebody else has discovered it, the demands and desires of industrial physics will be able to restore him if he wants to be restored.[2]

[2] K. Darrow, *Am. J. Physics* 12, 62 (1944).

Exchange of Technical Knowledge

Another of the directions in which physics grows was described as the exchange of technical knowledge. This is so closely related to research as to be nearly inseparable from it. Most of the excellent and effective program of publication carried on by the American Institute of Physics on behalf of its member societies and on its own behalf is concerned with this exchange of knowledge among physicists. It is in response to an internal pressure resulting from the great expansion of research activity.

The related frontier on which external pressures are, at least potentially, the greatest threat to continued expansion is that which concerns the freedom of such interchange of information. The war with its attendant security restrictions quite properly imposed temporary restrictions on the free exchange of information. But these restrictions persist, and there will be few, if any, among us who will not agree that all scientific development will be greatly hampered by a policy of suppression, even if confined to only a few fields. To the extent that we believe in the desirability of continued expansion of research, we must safeguard our intellectual free speech.

Dissemination of Knowledge and Education

There are, however, other aspects of the exchange and dissemination of knowledge which, while not directly related to research, are also of paramount importance to the balanced expansion of the physicist's domain. The first of these is concerned with an interchange of knowledge between the field of physics and the other fields of activity which comprise our civilization. There should be a continuing inward flow of the best ideas and ideals from social and economic fields into our thinking; and, if physicists are to assume a place in the world of affairs corresponding to their place in the scientific world, there must be an effective means whereby physicists may make known among themselves and to others their considered reactions and opinions on matters related to physics.

The new journal, "Physics Today."—The American Institute of Physics, after long and serious consideration, is assuming the role of pioneer in this field and will shortly commence the publica-

tion of a new periodical, *Physics Today*. This is to be a semiprofessional publication serving as a news organ for the profession and also as a forum for the exchange of the thinking of physicists on all kinds of matters related to the nontechnical aspects of physics. This news of physics and the contributions of physicists to general scientific thinking should prove of interest to many persons in related fields of science and engineering and to that increasing group of thoughtful persons who recognize the importance of science and scientific thinking in modern civilization.

The new journal is designed to fill the gap between the technical physics journals and the popular magazines. The success or failure of *Physics Today* will depend not only on the capabilities of the editor and his immediate advisers but also upon contributions of physicists in general to the development of the journal. It can fulfill its unique function in American life only with the help of all physicists.

Education.—It is apparent that one of the functions of this new publication is essentially an educational one, and education is one of the frontiers of expansion of the physicist's domain. It has two principal aspects: the first is internal—the education of physicists by physicists; the second is external—the contributions of physics to general and adult education.

We have done a good job of training physicists, as our record of achievement in research shows. But there are several questions to which some sort of answer must be given by each of us in the light of our experience and judgment.

First, are we permitting specialization in physics to interfere seriously with the over-all education of a physicist? In other words, are we turning out trained rather than educated physicists?

Second, is it desirable that we, as members of a profession, establish minimum standards that must be met by those who wish to enter the profession? Much has been said on both sides of this question, which is not entirely separate from the first. Other professions have adopted minimum standards and are active in the accreditation of training programs, with varying degrees of success. A great deal of thought must be given to the matter before we can develop this territory with any hope of positive accomplishment that is creative rather than restrictive.

The purely quantitative aspect of expanded training for physicists is another matter of concern. There is every reason to believe that the supply of adequately trained physicists will fall far below demand for their services for some years to come. What can we do, as an organized profession, to improve this situation and still have some assurance that physicists will be not only well trained but also well educated? More directly to the point, perhaps, what are we prepared to do with the larger numbers of prospective physicists who, in accordance with the law of supply and demand, will be delivered to us? To what extent do we wish, as physicists and citizens, to support current movements toward direct or indirect Federal subsidization of higher education?

These and similar questions are of the greatest importance to physics as a science and as a profession. They cannot be disregarded if the expansion of physics is to be anything more than a mechanical response to purely external forces.

I should like now to point briefly to another frontier on which considerable expansion has taken place and on which much more might appropriately be done—the frontier of education, not for physics as a profession, but for all of our young men and women.

Contributions of physics to engineering education.—A relatively obvious portion is concerned with the contribution of physics to the education and training of other scientists and engineers. Considerable progress has been made in the last ten years in cooperation with engineering educators through the overtures of the American Association of Physics Teachers to the American Society for Engineering Education. Physics is now recognized as a division of the ASEE; and in 1948, for the third time, the summer meeting of the Association will be held jointly with the Division of Physics of the ASEE.

The rapid development of research and graduate work in engineering which has been given impetus by the experiences of the war will inevitably bring physics and engineering into closer association. Engineers as a group are just now beginning to see that the four-year engineering course furnishes no sound basis for graduate

study and that those students who are to go forward into graduate work must have better grounding in mathematics and basic science than has been provided by the traditional engineering curriculums. Mathematics, physics and chemistry must not be regarded lightly as "service courses." The basic physical sciences must permeate the whole structure of engineering education, at the graduate level as well as in preparation therefore. A long period of association with engineering educators will be necessary to alter sufficiently the prejudices on both sides which have interfered in the past.

Lack of recognition of a certain basic unity in the education of all scientists, both pure and applied, has, in my opinion, decreased the effectiveness of training in all fields of science. Should we not be more alert to the recognition of mutual common goals in all fields of science education and to the possibilities for cooperative effort in achieving these goals?

Contributions of physics to general education.—Currently receiving greater attention (at least of a verbal sort) than the relation of physics to other sciences and engineering is the vast and nearly unexplored region wherein lies the realization of the potential contribution of physics to general, nontechnical education. There was a time when physics, as natural philosophy, was a fully accepted, integral part of college-level education. With the coming of the elective system and with our own increasing preoccupation with the training of research men, physics lost its assured place in the college curriculum. We have worried in words about this situation for a good many years now. I sometimes feel, however, that our approach has held in it too much of a feeling of self-preservation and not enough of a desire to contribute and cooperate.

It has surprised and startled me that physicists should have failed so badly in making physics contribute to the general education of nonscientists. The general lack of understanding of science and particularly of its significance in modern civilization is ample evidence that we have failed. It seems to me that one of the reasons for our failure is that we have not used the objective approach to the problem that might be expected of us as educated scientists. Our approach has been almost that of an old-time doctor who prescribes only one kind of pill. He knows the pills are good because he uses them himself. Because of his single-minded belief in his pills he prescribes their use for any and all disorders, possibly on the basis that "physics is physics."

In our particular case we have carried in stock for years *the* elementary physics course—guaranteed to be the only genuine such course. We have had it administered to us and we administer it—sometimes with a little sugar coating to kill the taste—to everyone who comes to us for aid regardless of the nature of his complaint.

How many physicists know of the carefully controlled experimentation that went on in science at Ohio State University about 15 years ago? One of the enterprising younger men in the department of botany advocated that the freshman course in botany should be revamped and directed toward the needs of the 93 percent of students who did not go on with botany as a major. The older members of the staff were deeply concerned. They said that it would mean a separate course for prospective botanists or else the lowering of standards in the intermediate courses. However, after the objectives of the course were set out and the teaching directed toward the accomplishment of these objectives, the course was not only better for the nonmajors but also for the majors as well. In fact, so much more was accomplished in the freshman course than before that the second-year courses had to be stepped up several notches.

Except for a few scattered, imaginative physics teachers who have exerted altogether too little influence beyond their own campuses, we have stuck with the traditional elementary physics course and, because we knew it was a good introductory course for students going into science, we have attempted to use it with nothing more than minor changes to achieve objectives that are completely different. Naturally we have not succeeded.

We have not succeeded because we have gone at the whole matter in the wrong way. We have produced *the* elementary physics course and tried to rationalize its possible outcomes as the optimum contribution of physics to practically any kind of educational situation. What we need most vitally and urgently is, first, to determine, in cooperation with educators who see the whole field of general education in a different and possibly broader light, a set of desirable objectives which we think may be accomplished by a study of physics. Second, we must design one or more courses whose only reason for existence is to

reach the desired goals in the most positive and straightforward manner. The planning of such a program of physics for nonscientists must be a creative act and not merely a process of adapting traditional courses to give lip service to the objectives.

Now, of course, this is not a simple process. We have learned one aspect of physics, and it is sometimes difficult for us to see that what we have learned is not necessarily the most desirable thing for others. We must apply to the problem of education the objectivity which is supposed to characterize the trained scientist.

It seems highly unlikely that any uniform program of physics for general education can or should be agreed upon by everyone. There must be a multiplicity of approaches to these problems. We must remember that we are experimentalists and hence should be willing to experiment freely in educational matters as well as in technical matters. The thing that must be common to all our experiments is a goal, that of making physics and science a useful part of the education of everyone.

May I now be very blunt about this matter? What we need at this point is more action and less talk. Let us experiment with our ideas rather than simply discuss them. Then in the future, in the AMERICAN JOURNAL OF PHYSICS, we may see less discussion about what we should do and more helpful, detailed factual information about *demonstrations or examples of what various teachers have successfully done* in the perfection of courses to meet specific needs.

Professional Activities

It is evident that the development of organizations and organized activities in physics has been principally along lines concerned with the development of the science as a research field rather than of physicists as a professional group. To recognize this fact clearly one need only compare our organization with that of the American Bar Association or the American Medical Association or, choosing a more closely related example, with almost any of the engineering societies. This line of development is a natural outgrowth of, and perhaps has contributed to, preeminent concern with research. What development along professional lines has taken place has been, in recent years, mainly through the American Institute of Physics.

The present status of our frontier in this direction suggests a variety of questions. First, and perhaps most basic, is there a profession of physics in the same sense that there is a profession of civil engineering or law? To what extent should physicists develop for themselves a professional organization comparable to those in other fields? Do we want or need an organization through which we can deal with such professional problems as qualifications, group ethics and desirable conditions of employment? Do we want or need an organization through which, in external affairs, physicists may speak or act as a group rather than as individuals? If we want such an organization, should it be the American Institute of Physics or another organization working closely with it but unhampered by the legal restrictions now applying to the Institute?

Social Participation

Closely related to nontechnical professional problems is that of social participation—that is, the participation of physicists as a group, as well as individually, in all the affairs of the community, the state, and the nation. Social participation of physicists has been and continues to be confined largely to a few individuals who break through the boundaries of physics itself and take prominent parts in other affairs. Benjamin Franklin's activities were not confined to science, nor were those of Benjamin Thompson or David Rittenhouse. Similarly, today, we find occasional individuals trained in science assuming leadership in the administration of governmental and other activities, particularly those that had their origin in scientific development. Are there enough such men and is their contribution the maximum that can be expected of physicists?

There is a school of thought that holds that physicists possess particular potentialities for leadership, parly because of the breadth of their training in fundamentals and partly, perhaps, because the election of physics, with its rigorous disciplines, as a career is a screening process. Whether one holds this belief or not, it would seem reasonable that physics should be no less effective than engineering, law, or other professional training in developing qualities of

leadership and that physicists should, appropriately, be no less active in asserting leadership.

The increasingly technical nature of activities upon which the government is entering on a large scale demands technically trained leadership. Bills passed by Congress before the last adjournment created over 40 positions at salaries of from $12,000 to $15,000, a number of which represent the highest positions in the government concerned with scientific research and development. During 1947 the Federal Government spent money on scientific work at a rate almost twice the war average.

These enormous amounts of money, which are certain to be increased, cannot be expended effectively without competent persons in key positions. It is essential to our national welfare that physicists be willing to accept their part of this leadership.

If these great projects are effectively and intelligently guided so that their tremendous possibilities are realized, they will become one of the greatest forces in the development of science. If they are poorly led, the effect upon science and the national welfare will be disastrous.

Intelligent citizenship.—There can be no question that the minimum level of desirable, individual social participation is intelligent citizenship. The frontiers here, however, are so broad as to involve group participation as well as that of individuals. Do we believe strongly enough in what we preach—namely, that scientific training assists in the formation of intelligent judgment—to feel that we who have had a greater than average scientific training are qualified to assume leadership in nonscientific matters? If so, we have a very clear-cut responsibility for making this experienced judgment available to all.

Even if we do not grant ourselves the possession of superior capability for judgment, do we not still have an extraordinary responsibility for helping guide the social use of products of our scientific activities? How can we best carry out our responsibilities—as individuals and as a group?

The answers we give to these and to other questions will most certainly determine the nature and extent of the future expansion of physics and with equal certainty will affect, for better or for worse, the course of our civilization.

Zeeman's Discovery of the Electron

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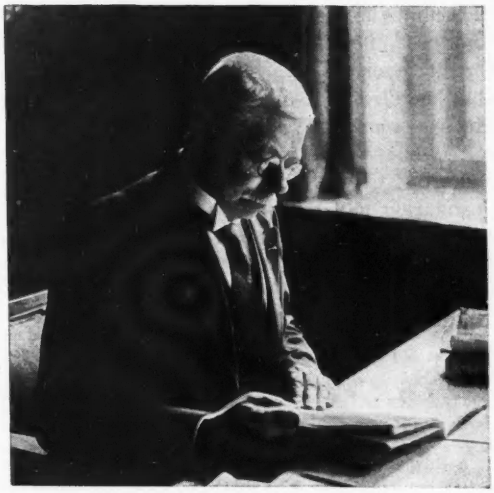
BETWEEN the summer of 1896 and the summer of 1897, the electron was discovered no less than four separate times by four independent observers. Working with cathode-ray beams, THOMSON, WIECHERT and KAUFMANN all found free, electrified particles having an e/m ratio some thousand times that of the hydrogen ion. As a representative of that group, THOMSON's discovery has recently been celebrated by the reprinting of his original announcement in the pages of this journal.[1] These three investigations make up what may be called the experimental discovery of the electron, for each one was designed to throw light on the earlier experiments of LENARD and RÖNTGEN, which had revealed the mysterious, penetrating radiations since known by their names. Moreover, THOMSON was led on to further experiments by which he discovered thermionic electrons and photoelectrons, and succeeded in measuring the electronic charge.[2] What may be called, by contrast, the theoretical discovery of the electron was the one made by ZEEMAN a few months earlier; for it was an idea born of theory which led ZEEMAN to it, and his discovery, in turn, served to introduce the electron to theoretical physics. Because of its importance from this point of view, it has seemed worth while also to reprint ZEEMAN's first paper,[3] "*On the influence of magnetism on the nature of the light emitted by a substance.*"

PIETER ZEEMAN (1865–1943), Docent at the University of Leiden and assistant in its Physical Laboratory, belonged to the FARADAY-MAXWELL school of the nineties, the group engaged in working out the consequences of the new electro-

[1] E. C. Watson, *Am. J. Physics* **15**, 458 (1947).

[2] A. Romer, *Isis* **34**, 150 (1942).

[3] P. Zeeman, *Phil. Mag.* (5) **43**, 226 (1897).



PIETER ZEEMAN (1865–1943). From a photograph obtained through the courtesy of Prof. C. J. Bakker, Director of the Zeeman Laboratory in Amsterdam.

magnetic theory, especially as it applied to light. He had made extensive and painstaking investigations of the magneto-optic Kerr effect, which he mentions in his paper; he had worked on the propagation of electromagnetic waves through liquids, and he had read and pondered. It was in August of 1896 when the opportunity came to try out his idea again.[4] He set to work, and ran off the first group of experiments in time to submit Sections 1 to 11 of this paper at the October 31 meeting of the Amsterdam Academy. His conference with LORENTZ and the subsequent observations on polarization followed immediately, so that Sections 12 to 25 were ready for the next meeting, four weeks later.[5] Early in 1897, the two Dutch papers were translated into English and sent as a single communication to OLIVER LODGE, editor of the *Philosophical Magazine*, who printed it in his March number.

H. A. LORENTZ (1853–1928), whose theory had so neat an interaction with ZEEMAN's experiments, was Professor of Theoretical Physics at Leiden. Since the days of his doctoral dissertation, he had been working at a detailed electromagnetic theory of light, first in HELMHOLTZ's formulation, later in MAXWELL's. He had been drawn to an "ionic" hypothesis to account for such phenomena as dispersion, the aberration of light and the manner of propagation of light in moving mediums. His "ions" were discrete electric charges, acting as intermediaries between the matter in which they were bound and the ever stationary ether through which light traveled.[6] The ionic theory, developed for other ends, proved competent to explain ZEEMAN's new phenomena and to predict others as yet unseen; in return, the experiments served to validate the theory and to define precisely the properties of the ions it employed. There was enough matter here for years of work.

Not only LORENTZ, but LARMOR, RIECKE and DRUDE were presently busy with electron theories (as they came to be called). Their immediate success was with dispersion and the optical properties of metals, with magnetism and with thermal and electrical conductivity.[7] Yet it was clear that such theories would be extended a great deal further, and that, when the time came, the theory of spectra and, consequently, of atomic structure would be an electron theory. Contemporary opinion, in fact, saw so much of promise that in 1902 the second Nobel Prize in physics was divided between ZEEMAN and LORENTZ. The first, it may be noted, had gone to RÖNTGEN.

LARMOR deserves an additional note in connection with ZEEMAN's discovery. He had been developing an "electron" theory[8] during the years immediately preceding.[9] His eye was consequently alert to catch the briefest notice of the new effect, but on calculation he found, imagining no electron less massive than a hydrogen ion, that it would be unobservable. Accordingly, in his next letter to LODGE, he mentioned it as interesting but dubious, and LODGE, with proper editorial caution, went into his laboratory to verify ZEEMAN's observations before he would print them.[10]

[4] H. Kamerlingh Onnes, *Physica* 1, 241 (1921).
[5] P. Zeeman, *Kgl. Akad. Wet. Amsterdam, Verslag., Wis.-Nat.* 5, 181, 242 (1896–97).

[6] J. Larmor, *Nature* 111, 1 (1923).
[7] N. R. Campbell, *Modern electrical theory* (Cambridge, 1907), pp. 47–134.
[8] He had got the word *electron* from FitzGerald, whose uncle, G. Johnstone Stoney, had coined it. It is thus exclusively Irish.
[9] J. Larmor, *Phil. Trans.* 185, 719 (1894); 186, 695 (1895).
[10] J. Larmor, *Mathematical and physical papers* (Cambridge, 1929), vol. 2, p. 140, footnote.

ZEEMAN tried to follow up his discovery, but he was handicapped by the poor facilities at Amsterdam, where he was called in January 1897. He did succeed in correcting the mistake he had made as to the sign of the charge carried by the emitters of light, and he thought that he had resolved the transverse triplet and longitudinal doublet when he used the fine blue line (λ4800A) in the spark spectrum of cadmium.[11] As a matter of fact, none of the lines he observed in his early work show the "normal" effect he expected, and it was perhaps fortunate for the immediate success of the theory that he failed to resolve the full structure at first. He saw some indications of "anomalous" patterns, but was anticipated in publication by PRESTON, CORNU and MICHELSON. Further investigation had to come at the hands of those with better instruments and more money.[12]

XXXII. On the Influence of Magnetism on the Nature of the Light Emitted by a Substance

DR. P. ZEEMAN*

Amsterdam, February 1897

1. Several years ago, in the course of my measurements concerning the Kerr phenomenon, it occurred to me whether the light of a flame if submitted to the action of magnetism would perhaps undergo any change. The train of reasoning by which I attempted to illustrate to myself the possibility of this is of minor importance at present,† at any rate I was induced thereby to try the experiment. With an extemporized apparatus the spectrum of a flame, coloured with sodium, placed between the poles of a Ruhmkorff electromagnet, was looked at. The result was negative. Probably I should not have tried this experiment again so soon had not my attention been drawn some two years ago to the following quotation from Maxwell's sketch of Faraday's life. Here (Maxwell, 'Collected Works,' ii. p. 790) we read:—"Before we describe this result we may mention that in 1862 he made the relation between magnetism and light the subject of his very last experimental work. He endeavoured, but in vain, to detect any change in the lines of the spectrum of a flame when the flame was acted on by a powerful magnet." If a Faraday‡ thought of the possibility of the above-mentioned relation, perhaps it might be yet worth while to try the experiment again with the excellent auxiliaries of spectroscopy of the present time, as I am not aware that it has been done by others.§ I will take the liberty of stating briefly to the readers of the Philosophical Magazine the results I have obtained up till now.

2. The electromagnet used was one made by Ruhmkorff and of medium size. The magnetizing current furnished by accumulators was in most of the cases 27 amperes, and could be raised to 35 amperes. The light used was analysed by a Rowland grating, with a radius of 10 ft., and with 14,938 lines per inch. The first spectrum was used, and observed with a micrometer eyepiece with a vertical cross-wire. An accurately adjustable slit is placed near the source of light under the influence of magnetism.

3. Between the paraboloidal poles of an electromagnet, the middle part of the flame from a Bunsen burner was placed. A piece of asbestos impregnated with common salt was put in the flame in such a manner that the two D-lines were seen as narrow and sharply defined lines on the dark ground. The distance between the poles was about 7 mm. If the current was put on, the two D-lines were distinctly widened. If the current was cut off they returned to their original position. The appearing and disappearing of the widening was simultaneous with the putting on and off of the current. The experiment could be repeated an indefinite number of times.

4. The flame of the Bunsen was next interchanged with a flame of coal-gas fed with oxygen. In the same manner as in §3, asbestos soaked with common salt was introduced into the flame. It ascended vertically between the poles. If the current was put on again the D-lines were widened, becoming perhaps three or four times their former width.

5. With the red lines of lithium, used as carbonate, wholly analogous phenomena were observed.

6. Possibly the observed phenomenon (§§3, 4, 5) will be regarded as nothing of any consequence. One may reason in this manner: widening of the lines of the spectrum of an incandescent vapour is caused by increasing the density of the radiating substance and by increasing the temperature.** Now, under the influence of the magnet, the outline of the flame is undoubtedly changed (as is easily seen) hence the temperature and possibly also the density of the vapour is changed. Hence one might be inclined to account in this manner for the phenomenon.

7. Another experiment is not so easily explained. A tube

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[11] P. Zeeman, *Kgl. Akad. Wet. Amsterdam, Verslag. Wis.-Nat.* 6, 13, 99, 260 (1897–98); *Phil. Mag.* (5) 44, 55, 255 (1897); 45, 197 (1898).

* Communicated by Prof. Oliver Lodge, F.R.S., with the remark that he had verified the author's results so far as related to emission spectra and their polarization.

† *Cf.* § 15 and § 16.

‡ See Appendix for Faraday's own description of the experiment.

§ See Appendix.

[12] P. Zeeman, *Researches in magneto-optics* (London, 1913), pp. 54–70.

** *Cf.*, however, also Pringsheim (Wied. *Ann.* xlv. p. 457, 1892).

of porcelain, glazed inside and outside, is placed horizontally between the poles with its axis perpendicular to the line joining the poles. The inner diameter of the tube is 18 mm., the outer one 22 mm. The length of the tube is 15 cm. Caps are screwed on at each end of the tube;†† these caps are closed by plates of parallel glass at one end, and are surrounded by little water-jackets. In this manner, by means of a current of water, the copper caps and the glass plates may be kept sufficiently cool while the porcelain tube is rendered incandescent. In the neighbourhood of the glass plates, side-tubes provided with taps are fastened to the copper caps. With a large Bunsen burner the tube could be made incandescent over a length of 8 cm. The light of an electric lamp, placed sideways at about two metres from the electromagnet, in order to avoid disturbing action on the arc, was made to pass through the tube by means of a metallic mirror. The spectrum of the arc was formed by means of the grating. With the eyepiece the D-lines are focussed. This may be done very accurately, as in the centre of the bright D-lines the narrow reversed lines are often seen. Now a piece of sodium was introduced into the tube. The Bunsen flame is ignited and the temperature begins to rise. A coloured vapour soon begins to fill the tube, being at first of a violet, then of a blue and green colour, and at last quite invisible to the naked eye. The absorption soon diminishes as the temperature is increased. The absorption is especially great in the neighbourhood of the D-lines. At last the two dark D-lines are visible. At this moment the poles of the electromagnet are pushed close to the tube, their distance now being about 24 mm. The absorption-lines now are rather sharp over the greater part of their length. At the top they are thicker, where the spectrum of the lower, denser vapours was observed. Immediately after the closing of the current the lines *widen* and are seemingly *blacker*; if the current is cut off they immediately recover their initial sharpness. The experiment could be repeated several times, till all the sodium had disappeared. The disappearance of the sodium is chiefly to be attributed to the chemical action between it and the glazing of the tube. For further experiments therefore unglazed tubes were used.

8. One may perhaps try to account for the last experiment (§7) in this direction:—It is true that the tube used was not of the same temperature at the top and at the bottom; further, it appears from the shape of the D-lines (§7) that the density of the vapour of sodium is different at different heights. Hence certainly convection-currents caused by difference of temperature between the top and bottom were present. Under certain plausible suppositions one may calculate that, by the putting on of the electromagnet, differences of pressure are originated in the tube of the same order of magnitude as those caused by the difference of temperature. Hence the magnetization will push *e.g.* the denser layer at the bottom in the direction of the axis of the tube. The lines become widened. For their width at a given height is chiefly determined by the number of incandescent particles at that height in the direction of the axis of the tube. Although this explanation still leaves some difficulties, certainly something may be said for it.

9. The explanation of the widening of the lines attempted in §8 is no longer applicable to the following variation of the experiment, in which an unglazed tube is used. The inner diameter of the tube, about 1 mm. thick, was 10 mm. The poles of the electromagnet could be moved till the distance was 14 mm. The tube now was heated by means of the blowpipe instead of with the Bunsen burner, and became in the middle part white hot. The blowpipe and the smaller diameter of the tube make it easier to bring the upper and lower parts to the same temperature. This is now higher than before (§7), and the sodium lines remain visible continuously.*** One now can wait till the density of the sodium vapour is the same at various heights. By rotating the tube continuously round its axis I have still further promoted this. The absorption-lines now are equally broad from the top to the bottom. When the electromagnet was put on, the absorption-lines immediately widened along their whole length. Now the explanation in the manner of §8 fails.

10. I should like to have studied the influence of magnetism on the spectrum of a solid. Oxide of erbium has, as was found by Bunsen or Bahr, the remarkable property of giving by incandescence a spectrum with bright lines. With the dispersion used, however, the edges of these lines were too indistinct to serve my purpose.

11. The different experiments from §§3 to 9 make it more and more probable that the absorption- and hence also the emission lines of an incandescent vapour are widened by the action of magnetism. Now if this is really the case, then by the action of magnetism on the free vibrations of the atoms, which are the cause of the line-spectrum, other vibrations of changed period must be superposed. That it is really inevitable to admit this specific action of magnetism is proved, I think, by the rest of the present paper.

12. From the representation I had formed to myself of the nature of the forces acting in the magnetic field on the atoms, it seemed to me to follow that with a band-spectrum and with external magnetic forces the phenomenon I had found with a line-spectrum would not occur.

It is, however, very probable that the difference between a band- and a line-spectrum is not of a quantitative but of a qualitative kind.††† In the case of a band-spectrum the molecules are complicated, in the case of a line-spectrum the widely separated molecules contain but a few atoms. Further investigation has shown that the representation I had formed of the cause of the widening in the case of a line-spectrum in the main was really true.

13. A glass tube, closed at both ends by glass plates with parallel faces and containing a piece of iodine, was placed between the poles of the Ruhmkorff electromagnet in the same manner as the tube of porcelain in §7. A small flame under the tube vaporized the iodine, the violet vapour filling the tube.

†† Pringsheim uses similar tubes in his investigation concerning the adiation of gases, *l. c.* p. 430.

*** Pringsheim, *l. c.* p. 456.

††† Kayser in Winkelmann's *Handbuch*, ii. 1, p. 421.

By means of electric light the absorption-spectrum could be examined. As the temperature is low this is the band-spectrum. With the high dispersion used, there are seen in the bands a very great number of fine dark lines. If the current round the magnet is closed, *no* change in the dark lines is observed, which is contrary to the result of the experiments with sodium vapour.

The absence of the phenomenon in this case supports the explanation, that even in the first experiment, with sodium vapour (§7), the convection-currents had no influence. For in the case now considered, the convection-currents originated by magnetism, which I believed to be possible in that case, apparently are insufficient to cause a change of the spectrum; yet, though I could not see it in the appearance of the absorption-lines (*cf.* §7), the band-spectrum is, like the line-spectrum, very sensible to changes of density and of temperature.

14. Although the means at my disposal did not enable me to execute more than a preliminary approximate measurement, I yet thought it of importance to determine approximately the value of the magnetic change of the period.

The widening of the sodium lines to both sides amounted to about 1/40 of the distance between the said lines, the intensity of the magnetic field being about 10^4 C.G.S. units. Hence follows a positive and negative magnetic change of 1/40,000 of the period.

15. The train of reasoning mentioned in (1), by which I was induced to search after an influence of magnetism, was at first the following:—If the hypothesis is true that in a magnetic field a rotatory motion of the æther is going on, the axis of rotation being in the direction of the magnetic forces (Kelvin and Maxwell), and if the radiation of light may be imagined as caused by the motion of the atoms, relative to the centre of mass of the molecule, revolving in all kinds of orbits, suppose for simplicity circles; then the period, or, what comes to the same, the time of describing the circumference of these circles, will be determined by the forces acting between the atoms, and then deviations of the period to both sides will occur through the influence of the perturbing forces between æther and atoms. The sign of the deviation of course will be determined by the direction of motion, as seen from along the lines of force. The deviation will be the greater the nearer the plane of the circle approximates to a position perpendicular to the lines of force.

16. Somewhat later I elucidated the subject by representing to myself the influence exercised on the period of a vibrating system if this is linked together with another in rapid rotatory motion. Lord Kelvin (now 40 years ago‡‡) gave the solution of the following problem:—Let the two ends of a cord of any length be attached to two points at the ends of a horizontal arm made to rotate round a vertical axis through its middle point at a constant angular velocity, and let a second cord bearing a material point be attached to the middle of the first cord. The motion now is investigated in the case when the point is infinitely little disturbed from its position of equilibrium. With great angular velocity the solution becomes rather simple. Circular vibrations of the point in contrary directions have slightly different periods. If for the double pendulum we substitute a luminiferous atom, and for the rotating arm the rotational motion about the magnetic lines of force, the relation of the mechanical problem to our case will be clear.

It need not be proved that the above-mentioned considerations are at most of any value as indications of somewhat analogous cases. I communicate them, however, because they were the first motive of my experiments.

17. A real explanation of the magnetic change of the period seemed to me to follow from Prof. Lorentz's theory.§§

In this theory it is assumed that in all bodies small electrically charged particles with a definite mass are present, that all electric phenomena are dependent upon the configuration and motion of these "ions," and that light-vibrations are vibrations of these ions. Then the charge, configuration, and motion of the ions completely determine the state of the æther. The said ion, moving in a magnetic field, experiences mechanical forces of the kind above mentioned, and these must explain the variation of the period. Prof. Lorentz, to whom I communicated these considerations, at once kindly informed me of the manner in which, according to his theory, the motion of an ion in a magnetic field is to be calculated, and pointed out to me that, if the explanation following from his theory be true, the edges of the lines of the spectrum ought to be circularly polarized. The amount of widening might then be used to determine the ratio between charge and mass, to be attributed in this theory to a particle giving out the vibrations of light.

The above-mentioned extremely remarkable conclusion of Prof. Lorentz relating to the state of polarization in the magnetically widened lines I have found to be fully confirmed by experiment (§20).

18. We shall now proceed to establish the equations of motion of a vibrating ion, when it is moving in the plane of (x,y) in a uniform magnetic field in which the magnetic force is everywhere parallel to the axis of z and equal to H. The axes are chosen so that if x is drawn to the east, y to the north, z is upwards. Let e be the charge (in electromagnetic measure) of the positively charged ion, m its mass. The equations of relative motion then are:—

$$\left.\begin{aligned} m\frac{d^2x}{dt^2} &= -k^2x + eH\frac{dy}{dt} \\ m\frac{d^2y}{dt^2} &= -k^2y - eH\frac{dx}{dt} \end{aligned}\right\}. \qquad (1)‡‡‡$$

The first term of the second member expresses the elastic force drawing back the ion to its position of equilibrium; the second term gives the mechanical force due to the

‡‡ Proc. Roy. Soc. 1856.

§§ Lorentz, *La Théorie électromagnétique de Maxwell.* Leyde, 1892; and *Versuch einer Theorie der electrischen und optischen Erscheinungen in bewegten Körpern.* Leiden, 1895.

‡‡‡ These equations are like those of the Foucault pendulum, and of course lead to similar results.

magnetic field. They are satisfied by

$$\left.\begin{aligned} x &= \alpha e^{st} \\ y &= \beta e^{st} \end{aligned}\right\}, \tag{2}$$

provided that

$$\left.\begin{aligned} ms^2\alpha &= -k^2\alpha + eHs\beta \\ ms^2\beta &= -k^2\beta - eHs\alpha \end{aligned}\right\} \tag{3}$$

where m, k, e are to be regarded as known quantities.

For us the period T is particularly interesting. If H = 0, it follows from (3) that

$$s = i\frac{k}{\sqrt{m}} = i\frac{2\pi}{T},$$

or

$$T = \frac{2\pi\sqrt{m}}{k}. \tag{4}$$

If H is not 0, it follows from (3) approximately that

$$s = i\frac{k}{\sqrt{m}}\left(1 \mp \frac{eH}{2k\sqrt{m}}\right).$$

Putting T′ for the period in this case, we have

$$T' = \frac{2\pi\sqrt{m}}{k}\left(1 \pm \frac{eH}{2k\sqrt{m}}\right). \tag{5}$$

Hence the ratio of the change of period to the original period becomes

$$\frac{eH}{2k\sqrt{m}} = \frac{e}{m}\cdot\frac{HT}{4\pi}. \tag{6}$$

A particular solution of (1) is that representing the motion of the ions in circles. If revolving in the positive direction (viz., in the direction of the hands of a watch for an observer standing at the side towards which the lines of force are running) the period is somewhat less than if revolving in the negative direction. The period in the first case is determined by the value of (5) with the minus sign, in the second with the plus.

The general solution of (1) shows that the ions describe, besides circles, also slowly rotating elliptical orbits. In the general case, the original motion of the ion having an arbitrary position in space, it is perfectly clear that the projection of the motion in the plane of (x,y) has the same character. The motion resolved in the direction of the axis of z is a simple harmonic motion, independent of and not disturbing the one in the plane of (x,y), and hence one not influenced by the magnetic forces. Of course, the consideration of the motion of an ion now given is only to be regarded as the very first sketch of the theory of luminiferous motions.

19. Imagine an observer looking at a flame placed in a magnetic field in a direction such that the lines of force run towards or from him.

Let us suppose that the said observer could see the very ions of §18 as they are revolving; then the following will be remarked:—There are some ions moving in circles and hence emitting circularly polarized light; if the motion is round in the positive direction the period will, for instance, be longer than with no magnetic field; if in the negative direction, shorter. There will also be ions seemingly stationary and really moving parallel to the lines of force with unaltered period. In the third place there are ions which seem to move in rotating elliptical orbits.

If one desires to know the state of the æther originated by the moving ions one may use the following rule, deduced by Prof. Lorentz from the general theory:—Let us suppose that in a molecule an ion P—of which the position of equilibrium is P_0—has two or more motions *at the same time*, viz. let the vector P_0P always be obtained by adding the vectors P_0P which should occur in each of the component motions at that moment; then the state in the æther at a very great distance in comparison with P_0P will be obtained by superposing the states which would occur in the two cases taken separately.

Hence it follows in the first place that a circular motion of an ion gives circularly polarized light to points on the axis of the circle.

Further, one may choose instead of the above-considered elliptical orbits a resolution more suited to our purpose. One may resolve the motion of the ion, existing before the putting on of the magnetic force, into a rectilinear harmonic motion parallel to the axis of z and two circular (right-handed and left-handed) motions in the plane of (x,y).

The first remains unchanged under the influence of the magnetic force, the periods of the last are changed.

By the action of the grating the vibrations originated by the motion of the ions are sorted according to the period, and hence the complete motion is broken up into three groups. The line will be a triplet. At any rate one may expect that the line of the spectrum will be wider than in the absence of the magnetic field, and that the edges will give out circularly-polarized light.§§§

20. A confirmation of the last conclusion may be certainly taken as a confirmation of the guiding idea of Prof. Lorentz's theory. To decide this point by experiment, the electromagnet of §2, but now with pierced poles, was placed so that the axes of the holes were in the same straight line with the centre of the grating. The sodium lines were observed with an eyepiece with a vertical cross-wire. Between the grating and the eyepiece were placed the quarter-undulation plate and nicol which I formerly used in my investigation of the light normally reflected from a polarly magnetized iron mirror.****

The plate and the nicol were placed relatively in such a manner that right-handed circularly-polarized light was quenched. Now according to the preceding the widened line must at one edge be right-handed circularly-polarized, at the other edge left-handed. By a rotation of the analyser over 90° the light that was first extinguished will be transmitted, and *vice versâ*. Or, if first the right edge of the line is visible in the apparatus, a reversal of the direction of the current makes the left edge visible. The cross-wire of the eyepiece was set in the bright line. At the reversal of the

§§§ I saw afterwards that Stoney, Trans. Roy. Soc. Dublin, iv., endeavours to explain the existence of doublets and triplets in a spectrum by the rotation of the elliptical orbits of the "electrons" under the influence of perturbing forces.

**** Zeeman, 'Communications of the Leyden Laboratory,' no. 15.

current the visible line moved! This experiment could be repeated any number of times.

21. A small variation of the preceding experiment is the following. With unchanged position of the quarter-wave plate the analyser is turned round. The widened line is then, during one revolution, twice wide and twice fine.

22. The electromagnet was turned 90° in a horizontal plane from the position of §20, the lines of force now being perpendicular to the line joining the slit with the grating. The edges of the widened line now appeared to be plane polarized, at least in so far as the present apparatus permitted to see, the plane of polarization being perpendicular to the line of the spectrum. This phenomenon is at once evident from the consideration §19. The circular orbits of the ions being perpendicular to the lines of force are now seen on their edges.

23. The experiments 20 to 22 may be regarded as a proof that the light-vibrations are caused by the motion of ions, as introduced by Prof. Lorentz in his theory of electricity. From the measured widening (§14) by means of relation (6), the ratio e/m may now be deduced. It thus appears that e/m is of the order of magnitude 10^7 electromagnetic C.G.S. units. Of course this result from theory is only to be considered as a first approximation.

24. It may be deduced from the experiment of §20 whether the positive or the negative ion revolves.

If the lines of force were running towards the grating, the right-handed circularly-polarized rays appeared to have the smaller period. Hence in connexion with §18 it follows that the positive ions revolve, or at least describe the greater orbit.

25. Now that the magnetization of the lines of a spectrum can be interpreted in the light of the theory of Prof. Lorentz, the further consideration of it becomes specially attractive. A series of further questions already present themselves. It seems very promising to investigate the motion of the ions for various substances, under varying circumstances of temperature and pressure, with varying intensities of the magnetization. Further inquiry must also decide as to how far the strong magnetic forces existing according to some at the surface of the sun may change its spectrum.

The experiments described have been made in the Physical Laboratory at Leyden, to the Director of which, Prof. Kamerlingh Onnes, I am under great obligations for continuous interest in the present subject.

Amsterdam, Jan. 1897.

Appendix

Since the publication of my original paper in the Proceedings of the Academy at Amsterdam, and while the present paper was in the press, I have become acquainted with two attempts, till now unknown to me, in the same direction, and also with the original account of Faraday's experiment referred to in §1. The last is to be found in Faraday's 'Life' by Dr. Bence Jones, vol. ii. p. 449 (1870), and as it is extremely remarkable I will reprint it here:—

"1862 was the last year of experimental research. Steinheil's apparatus for producing the spectrum of different substances gave a new method by which the action of magnetic poles upon light could be tried. In January he made himself familiar with the apparatus, and then he tried the action of the great magnet on the spectrum of chloride of sodium, chloride of barium, chloride of strontium, and chloride of lithium."

On March 12 he writes:—"Apparatus as on last day (January 28), but only ten pairs of voltaic battery for the electromagnet.

"The colourless gas-flame ascended between the poles of the magnet, and the salts of sodium, lithium, &c. were used to give colour. A Nicol's polarizer was placed just before the intense magnetic field, and an analyser at the other extreme of the apparatus. Then the electromagnet was made, and unmade, but not the slightest trace of effect on or change in the lines in the spectrum was observed in any position of polarizer or analyser.

"Two other pierced poles were adjusted at the magnet, the coloured flame established between them, and only that ray taken up by the optic apparatus which came to it along the axis of the poles, *i.e.* in the magnetic axis, or line of magnetic force. Then the electromagnet was excited and rendered neutral, but not the slightest effect on the polarized or unpolarized ray was observed."

"This was the last experimental research that Faraday made."

In 1875 we have a paper by Prof. Tait, who has kindly sent me a copy, "On a Possible Influence of Magnetism on the Absorption of Light, and some correlated subjects" (Proc. Roy. Soc. of Edinburgh, Session 1875–76, p. 118). Prof. Tait remarks that a paper by Professor Forbes, read at the Society, and some remarks upon it by Maxwell, have recalled to him an experiment tried by him several times, but which hitherto has led to no result. Then the paper proceeds:—

"The idea is briefly this.—The explanation of Faraday's rotation of the plane of polarization of light by a transparent diamagnetic requires, as shown by Thomson, molecular rotation of the luminiferous medium. The plane-polarized ray is broken up, while in the medium, into its circularly-polarized components, one of which rotates with the æther so as to have its period accelerated, the other against it in a retarded period. Now, suppose the medium to absorb one definite wave-length only, then—if the absorption is not interfered with by the magnetic action—the portion absorbed in one ray will be of a shorter, in the other of a longer, period than if there had been no magnetic force; and thus, what was originally a single dark absorption line might become a double line, the components being less dark than the single one."

Hence here the idea is perfectly clearly expressed of the experiment, tried in vain; an idea closely akin to that of §15 above, both being in fact founded on Kelvin's theory of the molecular rotation of the luminiferous medium, though not directly applicable to the experiment of §9, in which case the lines of magnetic force are perpendicular to the axis of the tube.

In the second place I have to mention two papers by the late M. Fievez, to which attention has been drawn by M. van Aubel, in a letter to Prof. Onnes and intended for

communication to the Academy of Sciences, Amsterdam. Prof. Onnes read the letter at the January meeting, and made at the same time some explanatory remarks of which in the following I make free and extensive use. The papers referred to are:—M. Fievez, "De l'Influence du Magnétisme sur les caractères des Raies spectrales" (*Bulletin de l'Acad. des Sciences de Belgique*, 3e série, tome ix. p. 381, 1885); and Fievez, "Essai sur l'Origine des Raies de Fraunhofer, en rapport avec la Constitution du Soleil" (*l. c.* 3e série, tome xii. p. 30, 1886). Here experiments are described as in §§4 and 13 of the present paper. Nothing, however, is observed about the widening of the absorption-lines, nor about the polarization of the emitted light. The results obtained by M. Fievez merit careful attention and consideration. He has observed with a flame in a magnetic field not only widening but reversal and double reversal of the lines of the spectrum, the lines at the same time becoming more brilliant. Unfortunately quantitative details are not given. The facts observed in some cases by Fievez are qualitatively not in accordance with my observations or what is to be deduced from my results. Hence even in the cases where the results are qualitatively in accordance, the question remains whether Fievez has observed *the same phenomenon*. The field used by Fievez seems to have been more intense than the one I had at my disposal. Is it possible perhaps to account in this manner for the "double renversement (c'est-à-dire l'apparition d'une raie brillante au millieu de la raie noire élargie)"? I think the answer must be in the negative. For, arguing from §19, a line must widen, or else, the field being very intense, become a triplet. We cannot but understand from Fievez's description of the experiment that the light was emitted perpendicular to the lines of force. Now the double reversed line of Fievez is not the triplet to be expected from theory, for it is expressly stated by Fievez that the line experimented upon is not the simple line of the spectrum, but one previously widened and reversed (by some agency independent of magnetism). By the action of magnetism a brilliant line in the centre of the black line appears. Hence perhaps one may interpret the case of double reversal as a direct action of magnetism, but then only as a doubling of the absorption-line and not as a division of the original line into three parts. As the application of Lorentz's theory given in §18 is confessedly only a very first sketch, further theoretical and experimental evidence is wanted before we are able to decide whether in the experiment of Fievez a specific action of magnetism on light or perturbing circumstances have been prevalent. Indeed one may make the same objection to M. Fievez's experiment as I myself have made to my own analogous experiment in §6.

The whole of the phenomena observed by Fievez can readily be attributed to a change of temperature by the well-known actions of the field upon the flame (change in its direction or outline, magnetic convection, &c.); and the last sentence of his paper states that "les phénomènes qui se manifestent sous l'action du magnétisme sont identiquement les mêmes que ceux produits par une élévation de température." The negative result obtained by Fievez with absorption-spectra would without further consideration (as in §12) point in the same direction. The inference to be drawn from Fievez's experiments alone would rather be, I think, that the temperature of the flame is changed in his experiments than that a specific action of magnetism on the emission and absorption of light exists. By experiments already in progress I hope to settle the dubious points.

Summarizing we may say:—Had the experiments of Fievez come to my knowledge they would have been a motive for me to further investigation, Fievez not having prosecuted his inquiry up to a decisive result. At least at present it remains even doubtful whether the phenomenon observed by Fievez with a magnetized flame is really to be attributed to *the specific action of the magnetic field on the period of the vibrations of light*, which I have found and undoubtedly proved by the experimental confirmation of Lorentz's predictions.

Amsterdam.

The *Un*clouded Crystal Ball

Too many men of science had said: "I am not interested in politics." Now the politicians have become too interested in the men of science, and as a result many had found themselves in custody, and their books burnt. Science has a social value, and the man of science cannot wash his hands of his discoveries. It is his duty to see that they are used for the betterment of mankind, and not for its destruction. In future he must be continuously alert to insure that fascism does not reappear under some other name elsewhere in the world.—G. FOURNIER, quoted in *Nature* 152, 307 (1943). Reprinted from the May–June 1946 issue of AMERICAN JOURNAL OF PHYSICS.

Mass Production in the Elementary Electronics Laboratory

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BASIC electronics has become an established addition to the curriculum of many physics departments as a result of the interest in the subject stimulated by World War II. The planning of new laboratories and experiments to accommodate the flood of postwar students eager to learn the mysteries of the vacuum tube has accordingly become another of the headaches, as well as the pleasures, of undergraduate physics teachers. While there are in operation many excellent laboratory courses for neophytes in electronics, the one herein described may be of interest both because its objectives and the conditions under which it is offered are somewhat out of the ordinary, and because it represents an attempt to provide a large number of students with the opportunity to perform experiments individually in minimum time. The authors believe that there is no substitute in a beginning course in electronics for a considerable amount of individual laboratory work on the part of the student if he is to acquire any feel for and appreciation of the subject.

The electronics course at the United States Military Academy must conform to the instructional methods and the rigid time schedule prescribed for all subjects in the curriculum. A general discussion of the so-called "West Point system" as applied in the Department of Physics may be found in a previous issue of this journal.[1] Although electronics is taught by the Electricity Department rather than under physics, the differences in procedures and the training of instructors are comparatively minor. The course in electronics is required of all second classmen (juniors), and is offered during the second term. Previously, each cadet will have had a year of college physics and a 110-period survey course in electrical engineering. Enrolment fluctuates between 500 and 700 students over a period of years, depending upon the distribution of the over-all size of the cadet corps among the various classes. The laboratory period is limited to two hours, and under the rigid scheduling of the cadets' time the department is limited to two such periods daily. For an average class of 600 men a minimum of three academic days is thus required to run off an experiment, even in a laboratory that can accommodate more than 100 students at a time, working individually.

The problems which confronted the department in the design of its laboratory course were: (i) to provide an adequate number of experiments (about 20) in elementary electronics with apparatus available in at least 100 individual units for each experiment; (ii) to design the apparatus so as to enable the student to accomplish something worth while in a laboratory period limited to two hours, within which must be included the completion of the laboratory report; (iii) to make the experiments sufficiently flexible to stimulate the good students without overwhelming the weaker ones, since the spread in interest and ability is great in a group of 600 men *required* to study electronics.

The Laboratory

As a result of the foresight of Colonel C. L. Fenton, U. S. A., retired, then Professor and head of the Department of Electricity, a new laboratory with 140 individual positions was completed just in time to meet the needs of the postwar course. A detailed description of the laboratory facilities has already been published.[2] Figure 1 shows the general lay-out of the benches, with the distribution panels in the background. The power supplies are centralized wherever practical, with a system of considerable flexibility to distribute the power to the 140 positions. It is sufficient here merely to list the circuits at each position: 1 single-wire circuit; 3 two-wire circuits; 1 three-wire circuit; 1 duplex receptacle (115 v, a.c.); 1 high-frequency coaxial cable; 4 ground jacks.

The following power sources can be patched to these circuits as desired.

* Now at Washington University, St. Louis, Mo.
** Now at the University of Alabama, Tuscaloosa, Ala.
[1] B. W. Bartlett, "Physics at the United States Military Academy," *Am. J. Physics* 12, 78 (1944).
[2] P. M. Honnell and W. E. Strohm, *Elec. Engineering* (Feb. 1946).

Fixed voltages:

115 v, a.c., 60 cy/sec, single phase, 226-amp capacity;
208 v, a.c., 60 cy/sec, single phase, 150-amp capacity;
240 v, d.c., 150-amp capacity.

Adjustable voltages:

3 120-v, 200-amp hr storage batteries, tapped every 4 v;
2 0–115-v, a.c., 60 cy/sec, single-phase variable transformers, 50 amp each, with isolating transformers permanently in tandem;
1 selenium rectifier, 0–60 v, d.c., 5-amp capacity at 60 v.

Audiofrequency:

1 beat-frequency oscillator, 20 to 40,000 cy/sec, 1-w maximum output;
2 booster amplifiers useful to 10,000 cy/sec, each 60-w output.

Radiofrequency:

4 oscillators, 300 w each, 2 to 18 Mcy/sec, any two of which can be connected to modulators capable of 100-percent modulation;
1 oscillator, 600 w, 150 to 500 kcy/sec, also capable of 100-percent modulation.

List of Experiments

The selection of topics for the experiments has been influenced in some degree by the peculiar educational needs of future Army officers. For some of them this will be the terminal as well as the initial course in electronics. Others will continue their study in this field, both in practical courses in Army branch schools and as post-graduate students in civilian engineering schools and universities. While a few of the topics, such as telephone and telegraph circuits, are included because of their military application, the emphasis throughout is upon fundamental principles.

In order that each cadet may complete a reasonable amount of work, including the write-up of his experiment, in the two-hour laboratory period, he is required to spend about one hour before coming to the laboratory in the preparation and completion of a preliminary report. Questions on the preliminary report are designed both to familiarize the cadet with the circuits involved and to bring out the point of the experiment.

In the majority of the experiments there is included a so-called "instructor demonstration." The instructor demonstration is normally a single set of apparatus—one to each 16-man laboratory section—set up by the instructor and designed either to review and emphasize the point of the experiment or to provide the cadet an opportunity to observe some phenomenon requiring apparatus that he would be unable to assemble for himself in the time allotted. Usually each cadet is required to operate the instructor demonstration and answer brief questions based on its behavior.

The sequence of experiments is such that they naturally fall into five groups. The list of topics follows.

I. Familiarization with Simple Communications Networks

EXP. 1. *A.c. impedance bridges.* Assembly of and measurements with fundamental bridge circuits.

Instructor demonstration: example of commercial bridge (General Radio 650A impedance bridge).

EXP. 2. *Attenuators and filters.* Assembly of and loss measurements on T and pi-attenuators; construction and transmission characteristics of simple low-, high-, and band-pass filters.

Instructor demonstration: separation of superimposed frequencies by means of filters.

II. Basic Vacuum-Tube Characteristics

EXP. 3. *Diode and triode.* Static and dynamic characteristics of diode and triode, including determination of tube parameters.

Instructor demonstration: special triode with fluorescent plate.

EXP. 4. *Multi-element tubes.* Static and dynamic characteristics of a tetrode and a pentode, including load-line computations and correlation with experimental data.

Instructor demonstration: amplifier unstable with triode, stable with pentode.

EXP. 5. *The cathode-ray tube.* General characteristics of commercial cathode-ray oscilloscope, and its application to measurement of voltage and frequency; linear sweep circuits.

FIG. 1. Electronics laboratory, U. S. Military Academy.

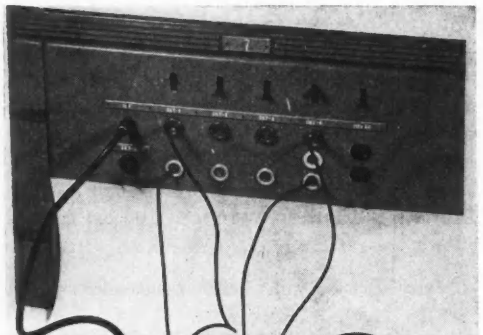

FIG. 2. Electronics circuit board at individual bench position.

Instructor demonstration: cathode-ray demonstrator board illustrating focusing and electric and magnetic deflection.

EXP. 6. *Photocells.* Characteristic curves; photocell with triode amplifier; relay operation; time-delay relay operation.

EXP. 7. *Gas-filled tubes.* Cold-cathode diode as half-wave rectifier; voltage regulator; thyratron firing characteristics and relay operation; grid-controlled thyratron rectifier, amplitude control and phase control.

III. Military Communications Circuits

EXP. 8. *Telephone circuits.* Test on components of local battery telephones; antisidetone circuits; voice-powered telephone.

EXP. 9. *Telegraph circuits.* Test on components of simple military telegraph set; a.c. and d.c. carrier telegraphy.

Instructor demonstration: simplexed and phantomed circuits.

IV. Basic Communications Component Circuits

EXP. 10. *Rectifiers.* Full-wave rectifier; load test, conversion efficiency and a.c. ripple with various filters; voltage-doubler load test; bridge-rectifier load test.

Instructor demonstration: wave forms and effects of simple filters.

EXP. 11. *A.f. Amplifiers, Part I* (class *A*, single ended). Resistor-coupled amplifiers; use of transformer for matching to load.

Instructor demonstration: frequency characteristics of audio amplifiers.

EXP. 12. *A.f. amplifiers, Part II* (push-pull, classes *A* and *B*). Push-pull amplifier, class *A* and class *B* operating characteristics.

Instructor demonstration: tone and volume controls.

EXP. 13. *Oscillators. LC* oscillators, tuned-plate, tuned-grid, Hartley and Colpitts.

Instructor demonstration: RC oscillator (limits of oscillation).

EXP. 14. *R.f. tuned circuits.* Selectivity curves of tuned circuits; measurement of *L*, *C* and *R* at radiofrequency; check on values of *L*, *C* and *R*, using commercial bridge.

EXP. 15. *R.f. coupled circuits and vacuum-tube voltmeters.* Construction and calibration of r.f. vacuum-tube voltmeter; selectivity curves with varying degrees of coupling, using vacuum-tube voltmeter.

EXP. 16. *R.f. amplifier.* Properties of class *C* amplifiers; load test and efficiency, using grease-spot photometer to measure r.f. output; harmonic generation.

Instructor demonstration: plate modulation of amplifier.

EXP. 17. *R.f. oscillator (use of crystal control).* Hartley, output and conversion efficiency; crystal control; conditions of oscillation; electron-coupled crystal oscillator.

Instructor demonstration: inspection of 1-kw laboratory oscillator.

EXP. 18. *Demodulation.* Diode demodulation, sensitivity and wave forms; plate demodulation, sensitivity and wave forms; grid-leak demodulation, sensitivity and wave forms.

V. Complete R.F. Communications Systems

EXP. 19. *Receiver and transmitter.* Construction of amplitude-modulation receiver.

Instructor demonstration: amplitude-modulation transmitter.

Apparatus

The problem of acquiring sufficient apparatus for the simultaneous performance of each of the experiments in the foregoing list at 140 individual positions was of no mean proportions. The department was extremely fortunate in two respects. First, shortly after V-J Day with the generous cooperation of Major General H. C. Ingles, Chief Signal Officer, U. S. A., it was able to acquire very substantial quantities of surplus Signal Corps equipment in lots of at least 120 each. Second, it had at its disposal a well-equipped machine shop, with adequate operating personnel to permit the assembling and mounting over a two-year period of all the apparatus designed for use in the sequence of experiments.

The basic item of apparatus is the electronics circuit board. Figure 2 shows this board with typical connections to a bench position. To save time all connections are made by slightly tapered

pin plugs and jacks. Standard circuit elements (fixed resistors, inductors and capacitors) are mounted inside of wooden blocks fitted with banana plugs, and can be plugged into uniformly spaced brass terminal strips on the board. Approximately 150 boards are required for the full program of experiments. Since a variety of tubes are used with the board, provision is made for the insertion of tube cards, indicating the connections of the tube elements to the circuit board, into a card holder (just in front of the tube socket in Fig. 2).

Figure 3 shows one each of the entire set of apparatus assembled or mounted in the department shop. In the top row from left to right are the telephone board, the telegraph board, the instructor demonstration apparatus for the cathode-ray oscillograph experiment, the electronics board and the filter board. Naturally the plug-in circuit elements (grouped in the center of the photograph) are required in a wide variety of nominal values and in considerable quantity. The nature and function of the other items are fairly obvious. The r.f. coupling coil used in distributing 2-Mcy/sec voltages to the individual bench positions is the third item from the bottom on the right-hand side of the figure. The special features of its design and use have been described elsewhere.[2]

Typical Experiments

In general, the apparatus and procedures involved in the series of experiments previously listed are quite similar to corresponding experiments in wide use in the first course in electronics. Comments on a few of the experiments, which

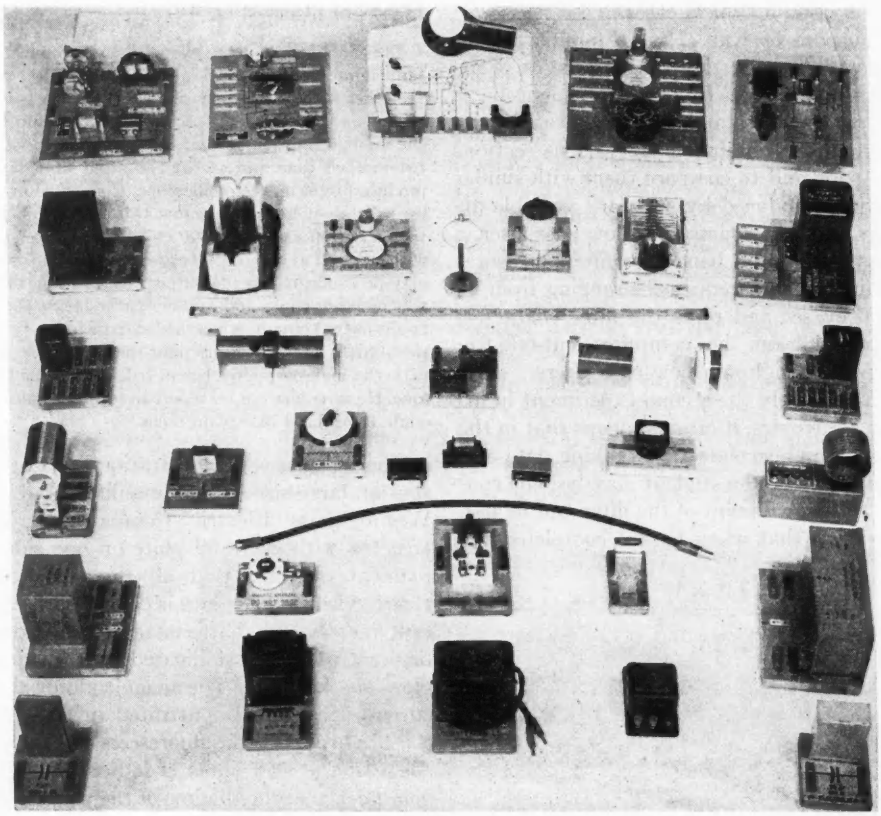

FIG. 3. Apparatus assembled in department shop.

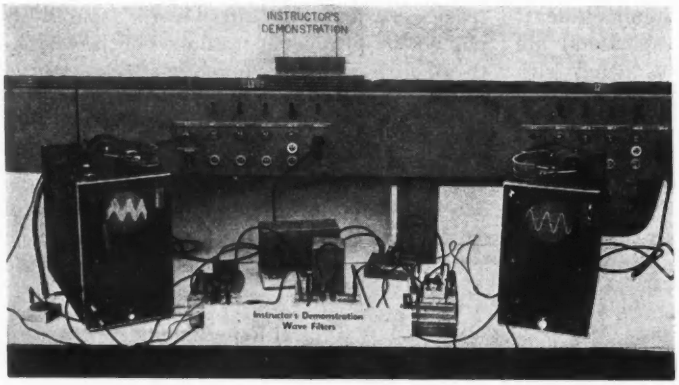

FIG. 4. Instructor demonstration, wave filters.

may be somewhat unique in the way in which they have been worked out for our special purposes, may be of interest and will serve to bring out the point of the so-called instructor demonstration in certain typical cases.

The purpose of EXP. 2 is to familiarize the student with the use and characteristics of attenuators and filters. In this experiment he is required to connect standard *T*-pads to measure the attenuations obtainable by various sections of these pads and to compare them with similar attenuations produced by standard variable attenuators. He then constructs a low-pass filter, a high-pass filter and a band-pass filter, measures the attenuations at frequencies ranging from 20 to 20,000 cy/sec and plots the filter characteristics. In addition, he computes cut-off frequencies of the high- and low-pass filters.

Since this is only the second experiment in his course in electronics, it often happens that in the rush of making his connections, taking data and computing results, the student may become confused as to the real point of the filter and its use. To make sure that when he has completed the entire experiment he will carry away with him a clear conception of what a filter does, there is included finally an instructor demonstration of the separation of superimposed frequencies by means of filters (Fig. 4).

TABLE I.

150 electronics boards	120 2-Mcy/sec crystals
120 telegraph boards	25 high-pass filters
120 telephone boards	25 low-pass filters
25 Cathode-ray demonstrators	150 telephone handsets
25 filter boards	30 loudspeakers
210 octal sockets	60 Grease spot photometers
240 plug-in boards	140 voltage dividers, 5000 ohms, 50 w
120 mounted photocells	120 r.f. coupling coils
120 r.f. tuning units (coil and variable condenser)	480 transformers
120 fixed attenuators	120 telephone headsets
6 adjustable attenuators	120 telephone relays
100 magnetic counters	4000 miscellaneous fixed-value circuit elements (resistors, capacitors, chokes, etc.)

The circuit consists of two oscillators connected to the same input circuit, one with a frequency of 500 cy/sec and the other with a frequency of 5000 cy/sec. A pair of headphones and a cathode-ray oscilloscope are connected across the input terminals, so that the student can listen to the two-pitched tone and see at the same time the pattern produced by it on the oscilloscope. Connected to the input by a double-pole, double-throw switch is a high-pass filter with a cut-off at about 2800 cy/sec, and a low-pass filter with a cut-off at about 2500 cy/sec. Either one or the other may be connected to the output, which leads to a second pair of headphones and another cathode-ray oscilloscope. In the output circuit, when the low-pass filter is connected, the student sees and hears only the 500-cy/sec tone, and with the high-pass filter connected, only the 5000-cy/sec tone. He is required in his report to record his observations qualitatively and to explain them.

The instructor demonstration for EXP. 3 is a special large-size triode manufactured by the Westinghouse Electric Company. It is constructed with grid and plate on one side of the filament only, so that all three elements are clearly visible. The plate is coated with a fluorescent material so that passage of electrons from filament to plate is indicated by the fluorescent glow on the plate. The magnitude of the plate current may be demonstrated qualitatively by the brightness of the fluorescence. The focusing effect of the grid wires is indicated by lack of fluorescence in the shadow of the wires. Behavior of the triode as an amplifier can be demonstrated visually by impressing a 20-cy/sec a.c. voltage on

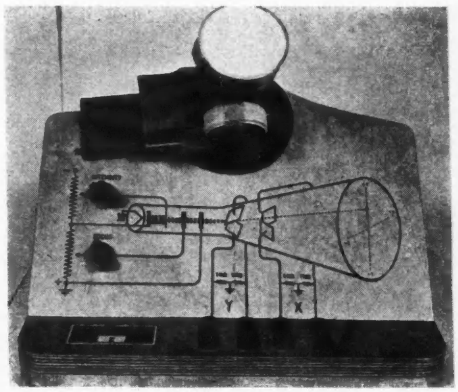

FIG. 5. Cathode-ray oscilloscope demonstrator.

the grid. At this low frequency the eye can follow the fluctuations of plate current with grid voltage as evidenced by changes in the fluorescence. Obviously, a variety of other demonstrations can be accomplished with this tube.

In this case, the instructor demonstration is presented to the group by the instructor prior to the start of the experiment, their first one involving the vacuum tube. We have found that it apparently clarifies the behavior of the tube in the mind of the student and tends to eliminate misconceptions arising from inability to visualize the material previously covered in the classroom on the tube characteristics.

The general purpose of EXP. 5 is to illustrate the operation and use of the standard 3-in. commercial cathode-ray oscilloscope. Here the instructor demonstration is designed to familiarize the student with what actually goes on inside the cathode-ray tube. Circuits are included in simplest possible form to illustrate focusing, electric deflections and magnetic deflections, using both a permanent magnet and deflecting coils. The cathode-ray demonstrator constructed in the department is shown in Fig. 5. The magnetic deflection coils shown in place may be replaced by a permanent magnet. Either arrangement may be rotated through 200° around the tube axis.

The series of experiments includes all the component parts of a simple radio receiver and transmitter. Experience shows, however, that the average student very often (and the poor student almost always) tends to be somewhat confused over the details of his first course in electronics, and therefore discouraged as to the real extent of his progress in the subject. To counteract any sense of defeat on the student's part, particular importance is attached to the last experiment in the series. In it the cadets work in teams and assemble a simple superheterodyne receiver utilizing components (blocks of the block diagram) which they have already studied in the previous experiments. Of a team of five men, one might construct the local oscillator, a second the first detector, another the second detector, the fourth the audio amplifier, and the fifth the i.f. circuit and other miscellaneous connections. They would then, as a group, assemble the whole into the complete receiver, using solely apparatus previously employed in their other experiments. This receiver actually can be used as a broadcast receiver.

The instructor demonstration for this experiment consists of an amplitude-modulation transmitter built up similarly from standard laboratory apparatus for each section. Using this transmitter, the cadets can actually talk between

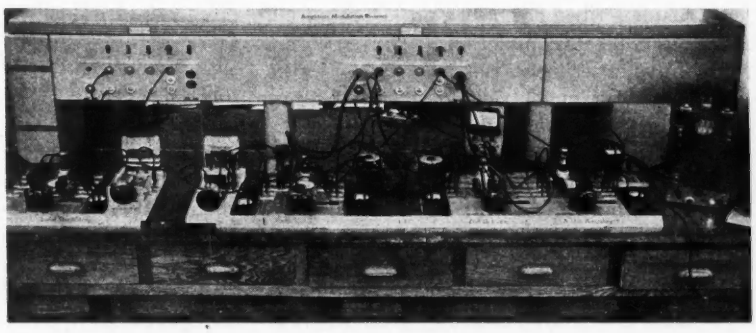

FIG. 6. Amplitude-modulation receiver.

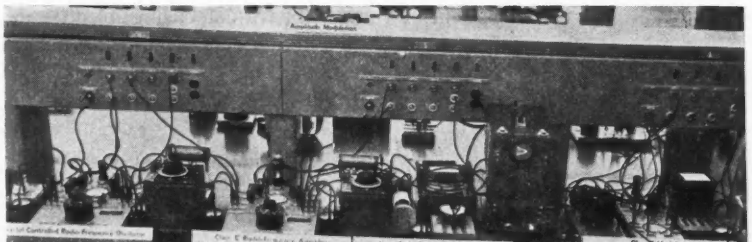

FIG. 7. Instructor demonstration, amplitude-modulation transmitter.

adjacent benches. For reference purposes, a single receiver is kept assembled and operative in the laboratory at all times so that the cadets can have a model for checking their own receiver if it does not function at first go. Figure 6 shows one of the electronics board receivers as it might be set up by a team of cadets, and Fig. 7 shows the corresponding transmitter for the instructor demonstration.

It has been our experience that this experiment is admirably suited to the purpose of summing up in the student's mind the results of his efforts in mastering the subject. Most groups of cadets are able with a little guidance from the instructor to complete the construction of the receiver and make it operate. We have found that after this experiment the morale in the classroom shows a definite upward trend. During graduation week, it is customary for the department to have an open house in its laboratories to which cadets can bring parents and friends to show off the equipment and what they know about it. The attendance and behavior of the cadets at this open house confirms our estimate of the value of this final experiment, in that they are generally eager to exhibit the department model of the superheterodyne and to explain that they themselves have been able to build just such a set.

Summary

The development of the electronics laboratory course just described has been a project requiring several years for its completion. It started with a group of five experiments designed for use in the abbreviated wartime curriculum at the Military Academy. As soon as it became evident that the postwar curriculum would include provision for a more extended study of electronics by every cadet, the authors set to work upon the development of the experiments and the procurement and design of the apparatus required. During the academic year 1946–1947 the series of experiments was presented in its entirety for the first time to a comparatively small class consisting of 300 cadets. This year for the first time the entire program is being conducted for a normal class of 600.

The fortunate circumstance that the 1946–1947 class numbered only 300 has enabled the department to utilize the two years in the entire manufacturing problem in its machine shop. Some idea of the magnitude of this problem can be obtained from the figures in Table I as to numbers of units required.

In addition, 120 of each of 3 ranges of calibrated voltage-divider resistors, 120 3-in. commercial cathode-ray oscillographs, 20 Hewlett-Packard audio oscillators, 60 decade resistors, 80 decade capacitors, and the usual ammeters and voltmeters were used, but were not constructed in our shop.

The authors feel that the unique features of the Military Academy course in electronics are:

(1) The successful utilization of centralized power sources, including a.f. and r.f. generators for the simultaneous operation of a maximum of 140 individual positions.

(2) The provision of an integrated set of component pieces of apparatus to make possible the individual performance simultaneously by as many as 120 students of the same set of 19 electronics experiments, thereby affording an opportunity for an entire class of as many as 720 men to take the same course.

(3) The development of short cuts in wiring procedures and in completion of the laboratory report which enable such experiments to be performed completely in a two-hour laboratory period.

(4) The use of the instructor demonstration as an adjunct to a better understanding of the experiment by the student.

Lest any reader interested in learning more of the details of our set-up be hesitant about visiting West Point because of its status as a military post, the department extends a cordial invitation to interested colleagues in the academic world to visit the Military Academy at any time the opportunity presents itself.

An Apparatus for Measuring the Velocity of Sound and Acoustic Absorption Coefficients

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THE standard method of measuring the velocity of sound in air in the elementary laboratory—by means of the Kundt tube—gives satisfactory results, but it is not very convenient. It is the purpose of this paper to describe a simple electrical version of this experiment that can be built of standard radio parts with a cash outlay of only a few dollars. The velocity measurements made with this apparatus are usually accurate to 0.2 percent after all important corrections are made. This apparatus has the further advantage of providing a new method of measuring the acoustic absorption coefficient of different materials.

Construction of the Apparatus

The sound is produced by a high-impedance earphone mounted at the end of a brass rod (Fig. 1). This earphone can be moved along the entire length of the glass tube. The glass tube is about 2 in. in diameter and is 4 ft long. The detector, or microphone, is a 2-in. permanent-magnet speaker mounted at the end of the glass tube. An earphone diaphragm is glued to the speaker cone, thus giving the air column a definite length and providing a good reflecting surface. The voice coil of the speaker is coupled to the oscilloscope by means of a radio-type output transformer. The earphone is energized by either an audio oscillator or a General Radio electrically driven tuning fork. For accurate velocity measurements the tuning fork should be used; for absorption studies, the audio oscillator is preferable, since the effect of frequency on absorption can easily be observed. The measurement of the output can be made most easily by means of a DuMont Type 264-A voltage calibrator used in conjunction with an oscilloscope.

Experimental Procedure

As the piston is moved along the tube, the earphone being energized, sharp maximums appear when the tube length is some multiple of a half wavelength. In order to measure the velocity of sound in air it is only necessary to measure the separation of these maximums. They are very sharp and are easily reproducible to a fraction of a millimeter. The ratio of the maximum amplitude to the minimum is about 15 to 1. This ratio is a function of the reflection coefficient of the surfaces.

Since this apparatus may be considered the acoustic equivalent of the Fabry-Perot interferometer, it is possible to use it in making absorption measurements. Thin samples of the material to be tested are cut in the form of disks and are fastened to the metal diaphragms forming the ends of the air column. These samples can be conveniently attached by glueing them to drafting tape which is attached directly to the metal disks. In this way, samples can be changed with very little effort. The materials of the disks thus become the reflecting surfaces and at the same time become part of the vibrating diaphragms of both the receiver and the source. The piston is then moved through slightly more than the distance between two successive maximums. From the ratio of the microphone responses at maximum and minimum we can compute the reflecting power and absorption coefficient of the material.

Theory

Velocity measurements.—The measurement of the velocity of sound consists merely of determining the wavelength of the sound wave of known frequency within the glass tube. There are

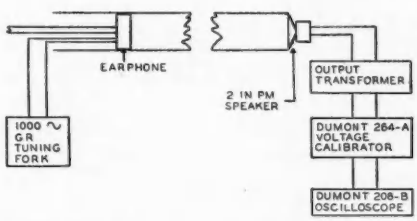

FIG. 1. Experimental arrangement for measuring wavelength and absorption coefficients of thin specimens.

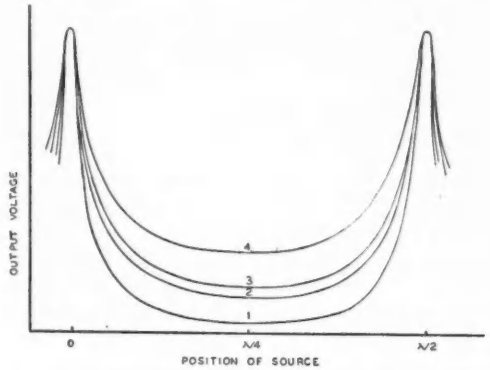

FIG. 2. Output voltage as a function of position of earphone (corrections applied to reduce all curves to the same maximums and to equalize successive maximums): *1*, acquered metal (earphone diaphragms); *2*, ⅛-in. balsa wood; *3*, $\frac{1}{16}$-in. cork; *4*, ¼-in. Celotex.

several significant corrections that must be made. In the first place, the wavelength of the sound wave within the tube is not the same as that of the same sound wave in open air, because the propagation of sound within a tube is not an adiabatic process. A correction for this effect must be made. Helmholtz[1] has calculated the effect of tube diameter on the velocity of sound in tubes and has stated the following relation:

$$v'=v\left[1-\frac{\left(\frac{\nu'}{4\pi N}\right)^{\frac{1}{2}}}{a}\right],$$

where v' is the velocity of sound in the tube; v, the velocity of sound in open air; N, the frequency; a, the tube diameter; and ν', the kinematic viscosity.

A second correction is introduced by the fact that the density of air is somewhat affected by the moisture content. The velocity of sound in a gas is given by the equation $v=(\gamma p/\rho)^{\frac{1}{2}}$. The value of γ, the ratio of the specific heats at constant pressure and constant volume, is practically the same for moist air as for dry air. The value of the density ρ, however, changes appreciably with moisture content. We may therefore write the approximate relation

$$v_d=v_m(\rho_m/\rho_d)^{\frac{1}{2}},$$

where the subscripts indicate the values of the velocity and density for moist and dry air. Finally, we reduce this corrected value to standard temperature by the equation

$$v_0=v_d(T_0/T)^{\frac{1}{2}}.$$

[1] H. von Helmholtz, *Crelle's J.* **57**, 1 (1859).

TABLE I. Acoustic absorption coefficients.

	r	A (measured values)	A (accepted values)
Lacquered metal	26	0.07	—
Balsa wood (⅛ in.)	8.2	.22	0.25*
Cork ($\frac{1}{16}$ in.)	6.6	.26	.31**
Celotex (¼ in.)	3.7	.43	.20–.70***

* For 7/16-in. thickness at 2048 cycle/sec.
** For 1-in. thickness.
*** Range of values depending on thickness and type of Celotex.

Absorption measurements.—The interference pattern observed when the length of the air column is varied continuously through two successive maximums is similar to those produced optically by the Fabry-Perot interferometer. The Fabry-Perot theory is discussed by Page[2] and will not be developed here. The equation relating the maximum and minimum intensities to the reflecting power is

$$\frac{I_{\min}}{I_{\max}}=\frac{(1-R)^2}{(1-R)^2+4R}=\left(\frac{1-R}{1+R}\right)^2,$$

where $I_{\min}$ and $I_{\max}$ represent the minimum and maximum intensities, and R the reflecting power. The potential difference developed by the type of microphone used in the present apparatus is approximately proportional to the excess pressure created by the sound waves. The intensity of the sound wave is, however, proportional to the square of the excess pressure. We may, therefore, write the foregoing equation in the form

$$E_{\min}/E_{\max}=(1-R)/(1+R),$$

where $E_{\max}$ and $E_{\min}$ represent the maximum and minimum output voltages. If we define $r\equiv E_{\max}/E_{\min}$, we have

$$R=(r-1)/(r+1).$$

Defining the acoustic absorption coefficient as $1-R\equiv A$, we have

$$A=2/(r+1).$$

[2] L. Page, *Introduction to theoretical physics* (Van Nostrand, 1935), p. 614.

Results

In studying the nature of the wave pattern within the tube, as a function of the tube length, the length of the air column is varied continuously through slightly more than the distance between two successive maximums, and the output voltage is measured. The patterns observed are indicated in Fig. 2. Such data are taken with several absorbers used as the reflecting surfaces. From the intensities of the maximums and minimums we can then compute the reflecting power and thus determine the absorption coefficient. Table I summarizes the acoustic absorption coefficients of several substances obtained from the data of Fig. 2. All measurements are made at a frequency of 1000 cycle/sec.

The Projection of Physical Experiments

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University of Saskatchewan, Saskatoon, Saskatchewan, Canada

THE use of demonstration apparatus in the presentation of lectures in physics is, or at least was, almost universal. In recent years, heavy enrolments have so increased the sizes of the classes in physics that many now include up to say 200 or 300 students. The demonstration apparatus generally available can be seen clearly by no more than perhaps 60 or 70, depending on the particular experiment shown. To meet this difficulty, some lecturers have resorted to the construction of important pieces of apparatus on a greatly enlarged scale. This may help considerably but introduces new difficulties—the increased labor and time required for the preparation of the lecture, the excessive storage space required, and the screening of the blackboard by the presence of such apparatus on the lecture table. Indeed, one is likely to give the demonstration out of its logical order, so that the apparatus can be removed; and this step itself introduces confusion and is time consuming.

An alternative plan—to make the apparatus very small and employ a projector—has long been in use generally for certain experiments. In the University of Saskatchewan this plan has recently been extended considerably to include a number of experiments not ordinarily projected. The projectors employed include a standard Bausch and Lomb horizontal type, with a regular 5×5-in. slot just in front of the lantern-slide carrier, and a Spencer vertical projector. For the former, the apparatus to be projected is mounted on 5×5-in. frames approximately $\frac{3}{8}$ in. thick, as shown in Fig. 1. Among the experiments adapted to the horizontal projector may be mentioned the following: simple pump; force pump (Fig. 1); siphon; Archimedes' principle; the rise (or depression) of liquids in capillary tubes; spherical drops in equilibrium; the formation of drops; capillary action on brushes; differential thermal expansion of communicating liquid columns; electrolysis of water; electrolytic formation (or disappearance) of lead "trees;" electroscopes; dancing helix; Barlow's wheel. In each case the experiment is performed; it is not a mere presentation of apparatus. Since in most of these experiments the image should be erect, an inverting prism is mounted in front of the projecting lens of the horizontal projector.

Certain experiments are suited better to the vertical projector, which offers also greater freedom as to size and mounting. Among those may be mentioned the horizontal surface-film phenomena of various types; the growth of crystals and some polarization demonstrations; motor-activated steel balls in a slightly inclined flat glass chamber to represent molecular action, one with uniform balls, another with a variety of sizes to represent particles of unequal masses; magnetic fields about magnets; magnetic fields about a vertical wire, making use of either iron filings or small compass needles; solenoids for use with and without iron cores; fields about combinations of coils; an operable Wheatstone bridge

(see Fig. 2). Other experiments would be suggested by the illustrations in the particular textbook used.

Some details as to materials and design may be of interest, even though they are not critical matters. The design of models requiring glass blowing may be determined by the skill and experience of the technician. It is unwise to have too many clamps holding the glass on the frames—two or three are generally sufficient. Models that require a transparent supporting sheet—such as those for magnetic fields and electric circuits—make use of clear Lucite stock, $\frac{1}{16}$ to $\frac{1}{8}$ in. in thickness.

A few details as to the construction of the Wheatstone bridge will serve to illustrate the general problem. The dimensions may be determined from the scale given in Fig. 2. The brass strips, $\frac{1}{16}$ in. thick, are fastened directly to the Lucite sheet by small flat-headed screws countersunk into the back of the Lucite; rivets would serve as well. For each of the coils, parallel rows of fine holes are drilled in the Lucite sheet, and the resistance coils are made by threading the wire through these holes; the ends are carefully soldered to the proper brass plates. The holes in the brass strips for receiving the brass plugs extend through the Lucite. Coils R, X and Y are made of manganin wire, Nos. 30, 36 and 34, and have resistances of 3.4, 5.7 and 4.1 ohms, respectively. The slide wire is No. 34; other sizes would do quite as well. There is a battery switch (not shown) mounted on the frame.

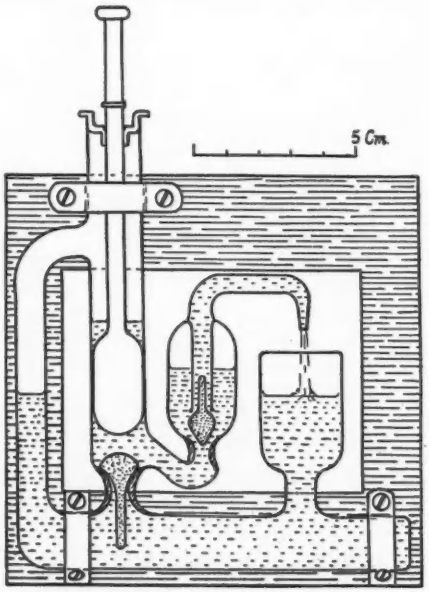

FIG. 1. Projection model of force pump. The extra tube at left of pump is for the return of any water that may get by the piston. Neither it nor the common base tube is projected.

The Barlow's wheel (Fig. 3) is particularly useful as a demonstration apparatus, since it is simple, shows real action and drives home its point. It is mounted on the standard frame and held in place by two brass plates as shown, the back one flat, the front with an offset sufficient to accommodate the length of the shaft carrying the wheel. The wheel B is made of an aluminum hub and disk, carrying 25-mil tungsten spokes, but without a rim. The spokes dip into a long Lucite trough M containing enough mercury to make contact with two spokes at a time. This trough is cradled between the two poles of an Alnico U magnet. A tinsel brush T, soldered to a supporting brass plate, and rubbing lightly on the shaft, serves to supplement the bearings in conducting the current to the wheel and thereby to prevent sparking which might damage the bearings. A single dry cell makes the wheel run slowly, two at optimum speed, three at a speed which blurs the spokes. Turning a reversing switch in the line causes the wheel to stop and reverse. Seeing a wheel on the screen as large as a wagon wheel start, stop and reverse, captures the attention of every student. Moreover, it is easier to demonstrate the hand rule for direction of motion and for the student to visualize what is taking place than it is with the usual disk, which in any case can be seen by only a fraction of the class.

When such apparatus is used for a demonstration, the blackboard is unobstructed, and it is easy to return to the experiment to clear up a point. Small racks provided with vertical slots make it possible to store many demonstration mounts within comparatively small spaces.

The projection of the solutions of problems is widely practiced, and has the advantage of

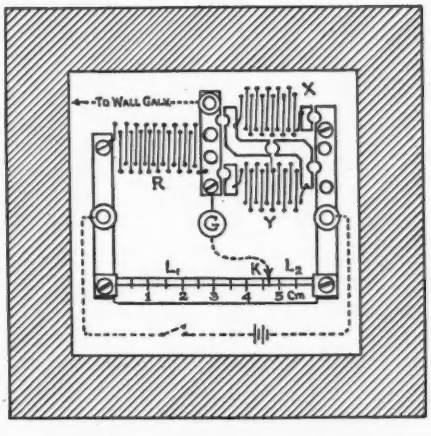

FIG. 2. Projection model of Wheatstone bridge. The movable contact point K is an insulated needle-like pointer held in the hand, while G is a wall galvanometer with a large scale, though they are represented by inked lines on the model. The unknown resistances can be measured singly, in series, or in parallel by the suitable use of four plugs.

clearing up points "while the iron is red," not some days later when the problem reader hands them back. The usual method is to coat one face of plain lantern-slide cover glasses with a 10-percent solution of ordinary gelatine; after drying these take ink as well as does paper.

Use is often made of a wax pencil on transparent plastics or even on glass, but the lines are hardly as clear cut as may be obtained by the ink on a gelatine-covered slide. However, the thin plastic sheets do lend themselves to the use of a typewriter. One has merely to draw a rectangle fixing the outer limits for the typing, on onionskin paper, which is placed on a sheet of plastic enclosed in the fold of a fresh sheet of carbon paper. The whole is inserted in the typewriter and the desired material typed on in the usual manner. Having the carbon paper on both sides of the plastic sheet gives sufficient density to the printing. Finally, the sheet is trimmed to lantern-slide size and mounted, either permanently or temporarily, between two lantern-slide cover glasses.

Such slides can also be used for review purposes. In one institution a well-known physicist lectured to classes of about 400 in a lecture hall that had no blackboard. He simply used a special vertical projector with large condensing lenses built into the desk, with a stack of coated plates, each about 7 in. square. Sitting at the projector, he would place a blank on the projector stage and write on it just as one would ordinarily write on a blackboard. Among the advantages mentioned were that the visibility was greatly enhanced, owing to the larger size of the writing and also to the relatively greater brightness of the screen, that less energy was required in lecturing, that no erasing was needed, and that it afforded the possibility of resuming on a topic left unfinished on the previous day without having to rewrite any needed introductory material. It made also for more efficient reviews.

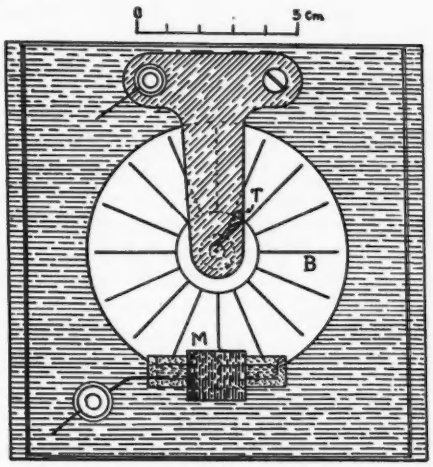

FIG. 3. Barlow's wheel. Tungsten spokes dip into a mercury pool placed between the two poles of an Alnico magnet *M*.

The author would appreciate receiving descriptive notes from any others who have been using the extended projection plan described here.

Change in Address of the Editorial Office

Manuscripts for publication in the AMERICAN JOURNAL OF PHYSICS should be submitted henceforth to Dr. Thomas H. Osgood, Michigan State College, East Lansing, Michigan. Doctor Osgood, the new editor [see *Am. J. Physics* **16**, 125 (1948)] will assume full responsibility for the JOURNAL as soon as the somewhat involved procedure of transferring the editorial work has been completed.—D. R.

Physics in the Predental and Premedical Curriculum

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Marquette University, Milwaukee 3, Wisconsin

THE importance of physics to dentistry and medicine is well known. To appreciate the scope of the application of the principles of physics to dentistry, we need only survey the work of Krogh, Holst and Henesy,[1] Gable,[2] Clark,[3] Thewlis[4] and others. In so doing we find that all fields of physics are represented, from mechanics to x-ray diffraction and radioactive tracers. Medicine affords a still more lucrative field. If we but examine the book *Medical physics*, edited by Glasser,[5] we immediately become aware of a tremendous new field of research and development presented to the medical profession by the physicist in the last 20 years.

The importance of physics in the predental and premedical curriculum is well evidenced by its adoption in the course of study by the 37 accredited dental schools and 72 accredited medical schools in the United States. Hence, the question is not whether physics should be included in the curriculum, but rather how it is to be taught, what is the science and mathematics background of the students and whether the number of hours devoted to it should be increased. Numerous articles[6–13] have been written on the subject of preparation for dental and medical schools, but since these articles present many controversial possibilities, no one has done much about the problems involved.

There exists in the universities at the present time a very common "disease," which we will call "Dento-medico curriculum tumor." This growth originated some 10 or 15 years ago, and its origin was simple and apparently harmless. Students who choose the medical profession as their vocational objective are quite naturally interested in studying those college subjects that will not only assist them in getting admission to a medical school, but will give them the best preparation for the difficult subjects in the medical course of study. Upon seeking advice as to which subjects are most likely to produce these results, students are frequently advised to elect courses in the natural sciences, especially zoology and chemistry, in addition to those normally required for admission to medical school. By so doing, they are told, they will enhance their chances for admission, and gain an advantage in the medical school over their college classmates who pursued a broad selection of courses or whose programs were composed predominantly of social or humanistic studies. This has resulted in a general extension of the premedical education from two years to three or even four years, and the predental education from two years to three. It has been shown[8] that by this procedure students may be misled into a sense of false security, for although they may gain admission to a medical school by studying advanced courses in science, they do not thereby improve their standing in courses in medicine.

The writer sent questionaries to the deans of all the accredited dental, medical and liberal arts colleges of universities in the United States having dental or medical schools, and to the chairmen of the physics departments of the institutions. Initially, the project was developed to form opinions for possible modifications in the Marquette University physics curriculum. The number and nature of the questions asked may not in all cases have been sufficient for a comprehensive study of the problem of a more effective teaching of physics among predental and premedical students. Since, however, the results proved interesting, it was decided to pass

[1] A. Krogh, J. G. Holst and G. Henesy, *Biol. Med.* **13**, 13 (1937).
[2] A. B. Gable, *J. Dental Research* **14**, 457 (1934); *ibid.*, *Dental Cosmos* **78**, 1021 (1936); *ibid.*, *J. App. Physics* **12**, 712 (1941).
[3] E. B. Clark, *Dental Digest* **37**, 55 (1931).
[4] J. Thewlis, *Brit. J. Radiol.* **9**, 101 (1936).
[5] O. Glasser, ed., *Medical physics* (Year Book Publishers, 1944).
[6] E. J. McGrath, *J. Dental Ed.* **7**, 46 (1942); *ibid.*, *J. Am. Assoc. Med. Coll.* **20**, 273 (1945).
[7] F. B. Mandeville, *J. Am. Assoc. Med. Coll.* **18**, 253 (1943).
[8] F. C. Zapffe, *38th year book* (Public School Pub. Co., Bloomington, Ill., 1938).
[9] R. W. Scott, *J. Am. Assoc. Med. Coll.* **18**, 356 (1943).
[10] F. H. Swett, *J. Am. Assoc. Med. Coll.* **19**, 206 (1944).
[11] W. T. Sanger and A. W. Hurd, *J. Am. Assoc. Med. Coll.* **21**, 8 (1946).
[12] R. W. Bunting, *J. Am. Dental Assoc.* **34**, 581 (1947).
[13] *Scalpel of Alpha Epsilon Delta* **17**, 97 (1947).

the information on to other groups planning to make a more thorough investigation of the problem.

The State of Affairs

In any attempt to correlate the physics requirements set up by the various universities and colleges, it is desirable to know the students' mathematics background. The following questions were therefore asked.

Liberal Arts Deans (70 percent reporting)

1. In admitting high school graduates to your predental or premedical division, how many units in mathematics and physics are required? (By a unit we mean one year of high school work in the subject.) *The results are tabulated in Table I.*

2. Does your premedical curriculum include any mathematics?

Semester hours of mathematics required:	0	2	3	4	5	6	8	10	12
Number reporting:	10	2	6	3	3	13	3	4	1

3. Does your predental curriculum include any mathematics?

Semester hours of mathematics required:	0	2	3	4	5	6	8	10	12
Number reporting:	19	2	5	1	2	10	2	1	1

4. If the answer to question 2 or 3 is no, and if it did not disrupt the curriculum too much, would you approve of having a mathematics analysis or survey course introduced in the premedical curriculum? *Yes*, 8; *no*, 2. In the predental curriculum? *Yes*, 12; *no*, 7.

From the foregoing set of answers, it appears that the majority of liberal arts deans favor a mathematical background for premedical and predental students.

TABLE I. Number of units of high school mathematics and physics required for entrance to preprofessional curriculums.

Curriculum	Units Required	Number Reporting* Mathematics	Physics
Premedical	0	4	33
	1	8	11
	2	29	1
	3	4	0
Predental	0	6	33
	1	7	9
	2	28	1
	3	2	0

* Here and in Tables IV and V, "Number reporting" refers to institutions.

Medical School Deans (77 percent reporting)

The following data relative to mathematics and physics were obtained from medical school deans. Of the 53 deans reporting, 31 favor 3 years and 22 favor 4 years of premedical work.

1. Would you be in favor of having a mathematics analysis or survey course introduced in the premedical curriculum? This course would be a survey of the important formulas, theorems, problems and applications of algebra and trigonometry. *Yes*, 36; *no*, 17.

2. Do you feel that the 8 hours of general physics now offered in your premedical curriculum are sufficient? *Yes*, 31; *no*, 22.

3. Would you be in favor of increasing the number of hours in physics from 8 to 12? *Yes*, 20; *no*, 27; *no answer*, 6.

The results of question 1 plainly indicate that mathematics is a desired requirement for the premedical student and is sanctioned by the medical deans. With the premedical curriculum increasing from two to three and four years, it is interesting to note that 22 of the 53 medical schools reporting favor an increase in physics in the course of study. This, in all probability, is owing to the recent marked development in electronic and nuclear physics and their application to medicine. Since these are very specialized fields and since radioactive substances, being dangerous, should be handled only by specialists, the following additional questions were asked.

4. If we divide the medical profession into two main groups—practitioners and specialists—do you feel that the latest discoveries on radioactive tracers, radiation treatment and so on have greater bearing on: *practitioners*, 0; *specialists*, 43; *both*, 8; *no answer*, 2.

5. If you checked "specialists" in question 4, do you believe that any knowledge of advanced physics required for the student's special field can be acquired during his graduate course of study? *Yes*, 34; *no*, 7; *no answer*, 12.

Medicine is a profession of specialists.[7] If the developments in atomic and nuclear research are to be of benefit to mankind, administration of

TABLE II. Subjects that could be curtailed in the premedical curriculum.

Subject	Order of preference 1	2	3
Philosophy	6	7	5
History	2	5	7
Modern language	14	6	6
English	0	0	1
Speech	3	4	2
Zoology, biology	8		

TABLE III. Subjects that should be emphasized in the premedical curriculum.

Subject	Order of preference 1	2	3	4
Chemistry	9	4	5	2
Zoology	2	3	4	8
Physics	8	6	5	1
Mathematics	8	6	3	2
Cultural	10			

TABLE IV. Number of hours of mathematics required as physics prerequisite.

Hours of mathematics, premedical	2	3	4	5	6	8	10
Number reporting	3	9	4	3	10	3	1
Hours of mathematics, predental	2	3	4	5	6	8	10
Number reporting	3	5	4	2	4	1	0

these benefits becomes a duty of the specialist. The need for more physics in the medical curriculum is obvious, but there is no agreement upon the time when this additional physics should be studied.

6. If the premedical curriculum had to be reorganized to include more hours of mathematics or physics, in which of the following fields could the cut best be made? Check any three, using the numbers 1, 2 and 3 in the order of your preference. *The results are tabulated in Table II.*

Zoology and biology did not appear on the original questionary, but were added after the results were tabulated. The general opinion of the eight deans reporting was, in effect, that students preparing for medicine need not begin to specialize at the college level.

7. In increasing the premedical requirement, in what department would you stress added work? Use the numbers 1, 2, 3 and 4 to designate your respective choice in the order of your preference. *The results are tabulated in Table III.*

Cultural subjects did not appear on the questionary, but ten deans were of the opinion that the premedical curriculum had sufficient science and needed more courses in other fields. From Table III it is apparent that more course work in physics and mathematics would be appreciated by the medical school deans.

The opinions of the various deans concerning premedical students, as expressed in the answers to the questionary, is of great importance. It directly affects some 15,000 students who are studying introductory college physics in the United States. Let us compare the status of the premedical student with that of the 24,000 engineering students in some 130 accredited colleges. All engineering students must meet definite mathematical requirements before taking physics. The reason is obvious—so that they may gain a better understanding of physics and its application to engineering and industrial problems. If the medical profession, in years to come, is going to rely more and more on physical developments and applications, then the physicians of the future should be prepared for that eventuality. Since a majority of liberal arts and medical school deans favor a strong mathematics and physics background, it should not be too difficult to find time for these subjects in the premedical curriculum.

Dental School Deans (97 percent reporting)

The following results were obtained from 33 deans regarding physics and mathematics in the dental school curriculum.

1. Do you feel that eight hours of general physics now being offered in your predental curriculum are sufficient? *Yes*, 30; *no*, 3.

2. Would you be in favor of having a mathematics analysis or survey course introduced in the predental curriculum? This course would be a survey of the important formulas, theorems, problems and applications of algebra and trigonometry. *Yes*, 13; *no*, 20.

3. Do you feel that two years of predental work are sufficient? *Twenty-four colleges preferred 2 years;* 5 colleges, 3 years; 4 colleges, 4 years.

It is apparent that the curriculum growth has not as yet reached the dental schools. A point of great concern, however, is the fact that although all reporting schools required physics in the predental curriculum, 60 percent of the deans feel that this can be studied satisfactorily with no more mathematics than that required for college entrance. It should be noted that this implies two years of high school mathematics studied three to six years ago. These results may have relatively little value taken alone, but how do they affect the various physics departments? It is the duty, pleasant and unpleasant, of the physics department to give as useful and applicable a course as possible. Ask any premedical or predental student what course causes him the most concern, and almost invariably he will answer "physics." The reasons given are many, but

most often are of the type: "Don't remember any mathematics; had it five years ago;" "Had no high school physics;" or the like. In trying to accommodate these students one slights, to the point of ignoring, the students who possess a good background, and to them the course becomes too easy and lacks a sufficient number of applications.

Question to heads of physics departments showed that 40 out of 45 colleges offered the same course to premedical and predental students, regardless of previous high school qualifications. How to accomplish some uniformity in the curriculums of these two colleges should be of the utmost concern to educators. Together the premedical and predental colleges "expose" some 20,000 students to physics each year, and for many students this means a hectic and sometimes futile struggle to surmount the one great hurdle that blocks the doors to the professional school. Before these doors open to the student, what resistance will the various physics departments have presented to him?

Physics Departments (70 percent reporting)

1. Does your institution require mathematics of premedical students? *Yes*, 33; *no*, 12. Of predental students? *Yes*, 19; *no*, 15.

If not, do you think they need more mathematics to get the most out of physics? Premedical: *Yes*, 11; *no*, 1. Predental: *Yes*, 14; *no*, 1.

For the departments that required mathematics, distribution of hours in the two curriculums is given in Table IV.

Eleven of the 12 departments not requiring mathematics felt that some mathematics is necessary to the premedical student for a better understanding and appreciation of the course. Five departments now requiring two or three hours of mathematics as a prerequisite to physics felt that this is insufficient. One department head thought that no mathematics was necessary, providing the students had had high school trigonometry. Fourteen of the 15 departments servicing the predental students thought that more mathematics is needed for a better understanding of physics.

One question related to the textbook used in the physics course. The results appear in Table V. A glance at this table will suffice to show the great variation that exists in the physics courses being taught to the predental and premedical students. Surely, an annual group of some 20,000 students is worthy of more uniformity in its physics courses.

TABLE V. Textbooks used in 57 physics courses servicing premedical and predental students.

Authors	Number reporting	Authors	Number reporting
Blackwood	2	Millikan, Roller and Watson	1
Brown	1	Perkins	3
Duff	3	Robeson	3
Eldridge	2	Saunders	2
Foley	4	Semat	2
Hausmann and Slack	2	Smith	4
Howe	4	Stewart	6
Kimball	1	Weber, *et al.*	2
Lemon and Ference	2	White	2
Lindsay	1	Wold	1
Mendenhall, *et al.*	9		

Probably the best remedy for this situation will come out of the important study now being conducted by the Committee on Physics for Students of Biology and Medicine.[14] Among other things, this committee advocates as one of the needs for a more effective teaching of physics for premedical and biological students (we may also include the predental students) a textbook oriented toward premedical and biological physics, to be used in a course that follows the regular introductory course. Such a course may be just what is needed to provide the additional work in physics suggested and recommended by the medical school deans and physics department heads.

In an effort to determine the reaction of physics department heads relative to an increase in hours in the premedical physics course of study, the following questions were asked.

TABLE VI. Distribution of time in the premedical and predental physics course.

Hours	0	1	2	3	4
Lecture	0	5	21	15	4
Quiz	5	26	14	0	0
Laboratory	0	6	17	16	6

[14] A committee of the American Association of Physics Teachers, formed to promote more effective teaching of physics among students of biology and medicine. The members are: L. L. Barnes, Cornell University (*chairman*); L. I. Bockstahler, Northwestern University; and L. A. Strait, University of California. See *Am. J. Physics* **14**, 338 (1946); **15**, 375 (1947).

2. In light of recent developments in electronic and nuclear physics and their application to medicine, do you think that 8 hours of general physics are sufficient for the premedical curriculum? *Yes*, 7; *no*, 38.

3. The general premedical physics requirement is 8 hours. Would you be in favor of increasing this number from 8 to 12, so as to include a 4-hour course in atomic and nuclear physics. *Yes*, 32; *no*, 7; *no answer*, 6.

The majority desire an increase in the number of hours, which agrees with the opinions of the medical deans. The nature of the increase, however, is open for discussion. Some suggestions were: (i) a course in modern physics; (ii) a course in modern and nuclear physics to be given in medical school; (iii) extend the course to 12 hours, but devote the extra time to fundamental physics presented in greater detail.

An attempted unification of curriculum should be accompanied by a similar unification in times allotted to lecture, quiz and laboratory. This will not be an easy task. The data in Table VI show a varied distribution of times. Some institutions reporting no quiz hours actually combine the quiz with the lecture.

It is too much to expect all predental and premedical physics departments to accept a common course of study, but some trend toward a uniform distribution of hours would be helpful in attaining the goal suggested above.

Conclusion

What is the picture before us? We are confronted with a problem that cannot just grow and become more confusing; its solution requires diligent planning. The premedical and predental curriculum in all colleges should provide for a minimum of three hours of mathematics as a prerequisite to college physics. This is desired by the majority of the medical school deans and strongly advocated by the physics department heads. In the growth of the curriculum from two to three and even four years, certainly time for three or even six hours of fundamental mathematics can be found.

Four to six additional hours of physics should be included in the course of study. This physics should consist of an extensive review of the many applications of physical principles to medicine and dentistry and a presentation of the modern developments of electronics and of atomic and nuclear physics. An undertaking of this kind can be accomplished only by wholehearted support of the project now being undertaken by the Association. The stipulated changes should be general enough to warrant their adoption as a necessary minimum requirement by all universities serving the professional schools.

The author acknowledges with sincere thanks the cooperation of his colleague Dr. J. B. Greene, of the Marquette University physics department, who gave suggestions and advice throughout this study. He also wishes to thank all the administrators who took time from their various activities to supply the information requested on the questionary. Space does not permit a discussion of the many fine suggestions sent to the author concerning this questionary. Suffice it to state that some necessary changes in the premedical and predental curriculum are urgently desired and wholeheartedly recommended.

Committee on Election Procedures

A committee of the American Association of Physics Teachers has been appointed to review the procedures of the Association in the nomination and election of officers, and to make recommendations for possible changes if these seem advisable The committee is anxious to have the views of members of the Association, either suggesting improvements or expressing approval of present methods. Communications addressed to Prof. Joseph D. Elder, Wabash College, Crawfordsville, Indiana will be welcomed by the committee and will receive its careful consideration.

Findings of the AAAS Cooperative Committee on the Teaching of Physics in American Universities

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THE Cooperative Committee for the Teaching of Science and Mathematics is a committee of the American Association for the Advancement of Science, on which K. Lark-Horovitz and G. W. Warner are the representatives of the American Association of Physics Teachers. One of the tasks of this committee was proposed to it at the end of February 1947 by the President's Scientific Research Board; this was to undertake a survey of science education in the United States, at all levels. As part of this survey, questionaries were sent to the presidents of the 50 institutions that award more than 90 percent of the Ph.D. degrees granted in this country. At the suggestion of M. H. Trytten, of the Office of Scientific Personnel of the National Research Council, the replies received from the physics departments of the participating institutions were transmitted to the writer for summary. A report based on the whole survey has been published in somewhat different form in volume four of the Steelman report.

The original questionary was prepared by K. Lark-Horovitz and R. W. Lefler, with the assistance of H. H. Remmers, all of Purdue University, and was submitted to the PSRB for distribution. The staff of the PSRB rearranged the questions, altering some of them and adding others, and changed the form of the questionary from one that could be answered by checking or filling in blanks to one that required answers in essay form.

The present summary is based on the replies received from the following 33 institutions:

Polytechnic Institute of Brooklyn
Brown University
California Institute of Technology
Catholic University of America
Columbia University
Harvard University
University of Illinois
Iowa State College
State University of Iowa
Indiana University
University of Kansas
Louisiana State University
Massachusetts Institute of Technology
Michigan State College
University of Minnesota
University of Missouri
New York University
University of North Carolina
Ohio State University
Pennsylvania State College
University of Pennsylvania
University of Pittsburgh
Princeton University
Purdue University
University of Rochester
Rutgers University
University of Southern California
Stanford University
University of Texas
University of Virginia
University of Washington
University of Wisconsin
Yale University

In more than one of the replies, an "answer" was not an answer to the specific question asked. It was evident from some of the replies that only half the question had been read, or that it had been misinterpreted; thus, for "effect" one person replying read "ill effect." It may be noted in passing that this is exactly what students are so often cautioned against and penalized for doing.

In the following summary, the questions have been copied from the questionary and are printed in italics, followed by a compilation of the answers. In some cases in which the question was in two parts, these parts and the answers to them are here given separately. No significance should be attached to the total number of answers to a particular question; not all of the departments replying answered all of the questions, and an answer of the form "yes, but..." was counted as affirmative and the qualification included. The first three questions included instructions to "differentiate between graduate and undergraduate teaching where appropriate."

1. Size of Enrolments

(*a*) *Has there been a significant change in the enrolments in your department since 1940?* Undergraduate: yes, 10; doubled, 11; tripled, 4. Graduate: yes, 16; no, 1. Increases up to fivefold were mentioned.

(*b*) *Has this change affected—one way or another—the quality of teaching in your department?* Quality lowered, 23; quality not lowered, 9. Three replies stated that elementary teaching was of lower quality but advanced teaching was not; one reply indicated just the reverse. Most of those who said that the quality had deteriorated gave as reasons that classes were too large and that the teachers were less competent than formerly. Several said space and equipment were inadequate.

(*c*) *If the effect has been negative, what measures have you taken—or do you intend to take—to counteract this effect?* Increase staff, 15; increase space and equipment, 9; hold conferences and discussions with new staff members; schedule classes at unusual hours.

If you have not taken such measures, please give reasons. Lack of funds for salaries or equipment; competition in salary with government and industry; inability to find staff; housing difficulties.

(*d*) *Are students being rejected from your department at the present time whom you would admit if classes were smaller?* Yes, 7; no, 18.

If so, in what proportion to those accepted? One institution rejected more than it accepted; others rejected from 10 to 50 percent. Of those that indicated whether their answer referred to undergraduate or graduate students, rejections were much higher among graduate than undergraduate students.

2. Space and Equipment

(*a*) *Is the quantity and state of repair of your instructional equipment a major limiting factor in determining the effectiveness of teaching in your department at present? Please give specific illustrations.* Yes, 15; no, 19. Five who answered "no" said that the chief limiting factor was lack of space.

(*b*) *What are the major factors which have determined your ability to procure and maintain needed equipment?* Low funds, 13; impossibility of procuring equipment, 12; shortage of skilled technicians, 6; lack of space for storage, 4; lack of time of staff and shop. Two departments built their own equipment. Some institutions reported that participation in war-training programs or government contracts provided them with adequate equipment.

(*c*) *Do you have sufficient funds to purchase needed equipment on the open market?* Yes, 18; no, 16.

(*d*) *To what extent is surplus space and scientific equipment (available through the War Assets Administration, Federal Works Agency, or other sources) of assistance to you in your teaching program?* Institutions that had war contracts seemed to fare very well with equipment, though it was mostly for research or shop. Seven said they had obtained some equipment; four said it was a great help. But 18 said they had got very little or no equipment that helped them in teaching. Four reported that no working space was offered.

(*e*) *Are space requirements an important limiting factor in determining the effectiveness of teaching in your department?* Yes, 17; no, 6. Six say that either research or graduate instruction are adversely affected.

Do you anticipate changes—one way or another—in permanent space available to you during, say, the next five years? Eight institutions have plans, and 8 have hopes for expansion; 4 report new laboratories under construction.

3. Availability of Teachers

(*a*) *How does your present staff compare with your prewar staff in numbers and competence? If there are significant changes, to what do you believe these changes to be due?* Staff increased, 12; about the same, 14; senior staff doubled, 4; senior staff unchanged, 6; junior staff tripled, 2; junior staff increased, 4; staff decreased, 1. Competence increased, 7; unchanged, 7; decreased, 9; competence of junior staff decreased but that of senior staff increased; great improvement in graduate teaching.

(*b*) *Has the competition for scientific personnel with industry, government or other universities affected the quality of your staff?* Very greatly, 3; yes, 20; no, 9.

What factors in this competition have operated to your advantage or disadvantage? Larger salaries or better conditions elsewhere, 5; salaries must be increased to keep good men, 3; staff is available, but not of quality desired; competition proves to the university authorities what must be done to keep good men; increased prestige of physics in the eyes of the authorities is a help in getting staff.

Do you believe that this competition is likely to continue? Yes, 14; until more Ph.D.'s are available, 7.

(*c*) *Do you feel that the present salary schedules of science teachers are likely to have an important influence on the quality of future science teachers? Please explain.* Higher salaries would lessen competition of Government and industry, 17; yes, 9; few now train for teaching because of low salaries, 5; unless salaries are increased, good research men may leave teaching, 3; salaries are rising to meet competition, 2; low prestige in elementary science teaching; in universities, more prestige for research than for teaching; unless salaries are improved the educational system of the country will be ruined; if the present high salaries continue, undesirable persons will be attracted to the profession.

(*d*) *How effective is science teaching at the graduate level for the training of teachers of science?* Excellent, 2; effective, 10; ineffective, 4; low for high school teachers; good for college teachers but hard on the students taught.

How might this effectiveness be improved? Emphasize social implications, 3; increase subject matter and reduce "education," 3; seminar method, 2; teach more history and philosophy of science; because present courses are too hard for high school teachers, more good training courses should be addressed to them; give more supervised practice in laboratory and recitation sections. One reply said that advanced courses are for research, not for teaching.

(*e*) *Do you feel it would be desirable to have more women teachers of science at the college and university level?* Yes, 2; no, 15; teachers should be chosen for merit, not sex, 5; no opinion, 4; makes no difference.

If so, what steps could be taken? What about other segments of the population? Competent women could teach in a men's college or university; not many women are interested in physics, 4; nepotism or kinship rules often prevent women from teaching, 2; women have little chance of appointment in a technical institute, 2.

4. Influence of the Federal Government

(*a*) *Are Federal contracts for research having any effect on the quality of science teaching in your department? If so, please explain.* No, 8; number of persons available for teaching reduced, 9; makes available good graduate teachers, 7; teaching more effective because more research being done, 6; good effect for participants, 6; students gain inspiration from contacts; takes away good women teachers; universities should not pay more for research than for teaching.

(*b*) *What policies do you believe educational institutions should follow in the acceptance of Federal contracts for research, including a consideration of the effects of such contracts on teaching?* Only fundamental research should be accepted, 11; work undertaken should fit the department's

own program, 9; contracts must not be permitted to reduce quality of teaching, 4; no secret work should be accepted; research workers should be required to do some teaching; contracts should not be allowed to affect university policy; contracts give helpful financial support; the number of contracts accepted must not be so large as to exclude research supported from other sources.

(*c*) *Have you been requested by the Federal Government to provide assistance in training their professional scientific employees?* Have done such training, 7; have done no training, 18; agreed to do training, but received no students.

If so, has this affected the quality of teaching in your department in any way? Quality unaffected, 4; declined to accept trainees because quality would be lowered; have accepted trainees only on merit.

5. Role of Research

(*a*) *Has the role of research in your department changed significantly since before the war? Are you, for example, doing more or less applied research as distinguished from fundamental research?* No change, 14; doing more research, all fundamental, 12; slightly more applied research, 3; did military research during war, 4; doing less research, all fundamental; doing no research because of loss of staff; kind of research changed, role the same; slightly more applied research now.

In your opinion, what has produced these changes? Administrative duties reduce time for research; only fundamental research was accepted; pressure of teaching, lack of space, loss of men; more cooperative projects now; attempts being made to wind up military contracts; quantity of research increased by extra funds.

(*b*) *If such changes have occurred, what is likely to be the effect on the quality of teaching?* Quality has improved, 4; graduate teaching is improved; undergraduate teaching will improve; quality suffers because more inexperienced men are now on staff; teaching candidates are being lost through competition.

(*c*) *Do members of your staff have adequate opportunities for research and study?* Yes, 18; no, 11. Some affirmative answers were qualified: teaching loads are too heavy; teachers work twelve months per year because they need the extra pay; some staff members have adequate opportunities but others do not; more staff members are needed.

6. Importance of Hired Technicians

(*a*) *Is the effectiveness of teaching influenced by the availability of hired technicians to perform subsidiary duties for the members of your faculty?* Yes, 32; no, 1; technicians save much staff time; they are helpful if they are good; good ones cannot be got at the salaries available; Federal contracts make such help possible.

(*b*) *Does the provision of technical assistants (glass blowers, mechanics, etc.) for your graduate students promote the quality of their scientific studies? Please explain.* Yes, 28; graduate students need help, but ought to do some technical work themselves, 16; technicians save time, 4; technicians make possible improved research equipment, 3.

(*c*) *To what extent do you have such assistance available?* Twice as much as before the war; technicians are used for laboratory and demonstration equipment; technicians are hard to get with limited funds.

Is it about the right amount? Yes, 7; fairly adequate, 5; not enough, 16. Several institutions are adequately staffed now but will need more in the future. Glass blowers seem to be specially needed.

7. General

(*a*) *Is sufficient attention being given, particularly in the undergraduate curriculum, to* (i) *the meaning and significance of the scientific method?* Yes, 13; no, 10; partly, 4. (ii) *the recent advances in the fields of science being studied?* Yes, 21; no, 4; partly, 1. (iii) *the fields of science related to the major field of study and overlapping fields as, for example, biophysics and geochemistry?* Yes, 11; no, 6; partly, 5. (iv) *the "general education" of the future scientist; training in other fields; training for citizenship?* Yes, 15; no, 7; partly, 4. Seven departments cite lack of time as the reason for answering in the negative; lack of funds or staff are also mentioned. Two departments say that scientific method cannot be taught directly.

(*b*) *This country has, in the past, produced about one-seventh of the Nobel prize winners in science. Do you consider this fact to be a reflection on the quality of science teaching in this country in the past? If so, please explain.* Yes, 11; no, 13. Reasons for an affirmative answer: mass education, though necessary in a democracy, does not help the brilliant student; the fault is primarily with secondary education, which is much less rigorous than in British or European schools, and students are too old by the time they get to advanced work to assimilate it; American education places too much emphasis on teaching and too little on learning, the burden being on the instructor rather than on the student. Those who replied in the negative suggest that the country is still young; that those who might now be awarded a Nobel prize are not those now in school or college; that brilliant individuals in this country tend to go into nonscientific pursuits; that teachers are held in low esteem by the public; that only recently has this country begun to emphasize fundamental rather than engineering or applied research; that the fraction cited is in error.

The real problem in the years ahead is one of making the most efficient use of all our national resources—and not the least of these resources is our intelligent youth.—GEORGE A. SLOAN.

Pasteur's Report on the Usefulness of the Historical Method in Teaching Science

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ON October 18, 1858, Louis Pasteur prepared a report entitled, "On the usefulness of the historical method in teaching science." It was addressed to the Inspector General of Education and was written by Pasteur in his capacity as Director of Scientific Studies in the École Normale Supérieure, Paris, which trains college and university professors for the whole of France. The translation that follows is based on the report as it appears in Pasteur's *Oeuvres* (Paris, 1939), Volume 7, pages 160–163.

It should be noted that in this report Pasteur uses the word "classic" less in the sense of "Greco-Roman" than in the sense of "accomplished, perfect."

ON THE USEFULNESS OF THE HISTORICAL METHOD IN TEACHING SCIENCE

LOUIS PASTEUR

It seems useful to me to submit to you some observations concerning the teaching of science in our school and concerning the direction which should be given to the efforts of third-year pupils in the most important part of their studies, that is, in the preparation of courses and in the best methods of teaching college classes.

These observations refer particularly to the teaching of the physical and natural sciences, although they might also be applied to mathematics. You may decide for yourself whether it is advantageous to communicate these observations to the professors. Personally, I have no delusions about the true character of leadership in the studies in this school. In an institution that has always had amongst its professors the most distinguished scientists of the capital, useful leadership in these studies consists, in my opinion, rather in helping to put into practice the advice of the professors than in controlling their teaching. The director has to improve studies mainly by maintaining the regulations and by intensifying the efforts of the students.

Nevertheless, the director of studies follows the progress of all pupils, assists in the examinations, assembles the grades and remarks of the different professors, and collects their individual observations. It must be admitted, therefore, that he is in a better position than anyone else to evaluate the results of the combined efforts of the school as well as the methods to which the students respond most readily, and the common quality and shortcomings of their mentality.

From this point of view, it seems to me that our pupils are not using a truly classic method when preparing their courses. It seems to me that they are beset by a danger that is unfortunately general and all the more serious as it is the habit of youth anyhow to overestimate the work and the men of our times to the neglect of our predecessors. There exists a tendency to regard science in its present state as being exclusively the work of contemporaries, although it has received from them only its most recent improvements. If we tolerate this evil, it will lead us directly to the loss of all traditions of a classic education. This situation must be remedied right here in the École Normale, because here all teaching methods must receive their greatest possible perfection.

In the sciences of observation, most questions have been the object of greatly varied studies; they have undergone numerous developments and have been enriched by rather secondary details and data. From this they have profited greatly; everything new is a gain to them. As Buffon said, we must collect facts in order to have ideas. But the teaching of a young professor is seriously endangered when he isn't careful and when he leaps without discrimination into this hodgepodge of data. He must remain aware of the fact that his first duty is to concentrate on what is truly classic in the science that he has been entrusted to teach; he must concentrate on all that is due to the real inventors.

It is said that our pupils are not willing to learn about the methods, the results, the apparatus of such and such scientists of the past. Therefore, in the discussion of a discovery, contemporary authors are generally preferred.

I know that most scientific discoveries can be described in a few words and demonstrated by a small number of decisive experiments. But if one tries to understand the origin of these discoveries, if he follows carefully their development, one is struck by the slowness with which they have come into being. Two different methods can therefore be adopted to present a discovery. One method consists in stating the law and in demonstrating it in its present expression without bothering about the way in which it has come to life. The other method, more historical, evokes the individual efforts of the most important inventors, adopts preferably their own terms, indicates their essentially simple procedures, and tries to transport the audience mentally into the period when the discovery was made. The first method sees primarily the fact, the law, and its practical usefulness. It hides from the young people the slow and progressive march of the human mind. It develops in them an expectation of sudden revolution in thought, and an unfounded admiration of certain men and certain actions. The second method illuminates the intelligence. It enlarges it, cultivates it, makes it capable

* The translator is indebted to his colleagues, Marshall Clagett and Robert Stauffer, Department of History of Science, and George Urdang, Department of Pharmacy, for improvements of his text.

of producing, and fashions it for new inventions. This second method shows that nothing durable is obtained without manifold effort. It gives to the mind the habit of honesty and invites the youth to be respectful of tradition and authority. To strengthen this method I would like to see reprinted, with the financial help of the various governments, the works of all the scientists who are the honor of their nations.

I would like to make this subject more explicit by an example. I will choose it from the teaching of chemistry, not because I think the teaching of chemistry in our school is worse than that of other subjects, but because this science is more familiar to me and I can therefore be more precise in the details. That the evil is general will become obvious enough.

The subject for the paper in chemistry for the last *concours d'agregation* was "cyanogen and cyanohydric acid." There is no doubt that the observations of Gay-Lussac (1815) concerning these two substances should be known and taught in preference to anything else. But, only two out of 23 candidates have described the classic apparatus with which this scientist prepared for the first time cyanohydric acid in its pure state. The majority, on the contrary, have indicated the procedure of I don't know what German chemist in using yellow prussiate (ferrocyanide of potassium) and sulfuric acid. Is that not a complete misunderstanding of the principles of a classic teaching procedure? An even more striking peculiarity is that none of these 23 papers has mentioned a fact which, according to Gay-Lussac himself, was essential to his fruitful discovery of cyanogen. I am speaking of the simple precaution of carefully drying the prussiate (cyanide) of mercury before submitting it to the action of heat. The products of the decomposition of prussiate (cyanide) of mercury under the influence of high temperatures had been studied a long time before Gay-Lussac. But, as the product had not been dried, the presence of water caused a complication that masked the simplicity of the principal phenomenon. Gay-Lussac himself states: "Monsieur Proust has employed a humid cyanide and I have employed a very dry one; if water had not been present he could hardly have avoided discovering cyanogen."

Should it, therefore, be permitted to talk in detail about cyanogen without insisting on the usefulness of drying the prussiate (cyanide) of mercury in the preparation of this gas? Since Gay-Lussac says himself that he owed his discovery to this precaution, is it not a classic fact of the first order in the history of this product? We should emphasize this fact, for better memorizing of the discovery if for no other reason.

This is also a salutary example with which to show to young minds that the finest work has very often the most humble origin and that attention devoted to facts which at first appearance seem of very little importance may lead to the greatest discoveries. It means a great deal to impregnate their minds in this way with the immutability of the laws of physical nature which ordain that the falling apple and the earth turning in its orbit are both subject to the law of universal attraction.

It would be superfluous to develop further my thought in this context. I close in stating that we can never impress strongly enough upon our pupils, by our example as well as by our advice, the fact that among the theories and data concerning a given subject, two parts have always to be separated: the classic facts, and those facts of which we don't yet know whether they will be classic or not. Our own pupils must concentrate on the former and (in their teaching in college) leave the latter to others. They must know that the best way to remain classic is to assimilate all in the work of the great inventors that has not aged beyond measure.

The Zodiacal Light

There glows in the nebulous west, at twilight,
An ethereal nimbus, as it shapes
And veils the horizon with chiffon drapes,
Like spin-drift, ere the coming of the night.
It lifts pale wings in the tropical sky
Like a downy bird about to fly—a light
That lures birds northward in their pathless flight,
Sensing the drift of summer drawing nigh.
It is the prophecy of spring—
The zodiacal light.

—M. C. Rundlett

Reproductions of Prints, Drawings and Paintings of Interest in the History of Physics

38. Illustrations from Marcus Marci's *De Proportione Motus*

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IN the preface to his *Science of Mechanics* ERNST MACH wrote as follows:

> In less immediate connection with the text stand the facsimile reproductions of old originals in my possession. The quaint and naive traits of the great inquirers, which find in them their expression, have always exerted upon me a refreshing influence in my studies, and I have desired that my readers should share this pleasure with me.[1]

Two of the most interesting facsimile reproductions in the *Science of Mechanics* are from MARCUS MARCI's *De Proportione Motus* (Prague, 1639). There are, however, several other plates in this rare work that are well worth reproducing. It is the purpose of this article to do so.

JOANNES MARCUS MARCI (1595–1667) (Plate 1) was a professor at Prague and a contemporary of GALILEO, from whom he probably obtained many of his ideas regarding the laws of motion. He was one of the most learned men of his time, as the two books of his still extant bear eloquent witness. His *Thaumantias. Liber de coelesti deque colorum apparentium natura, ortu et causis* (Prague, 1648) treats of the color phenomena associated with prisms and states "that the colors *originate in* refraction and that the *degree of refraction* determines the color."[2] He recommends observing the spectrum in a darkened room and makes the important observation that the color once obtained will always remain the same however much refracted. As pointed out by F. ROSENBERGER[3] he might have anticipated NEWTON if he had known the exact law of refraction.

MARCUS MARCI's knowledge of the laws of motion, as displayed in his *De Proportione Motus*, was equally advanced for his time. While he did not succeed in reaching as clear ideas re-

PLATE 1. Joannes Marcus Marci (1595–1667).

PLATE 2. Frontispiece to Marcus Marci's *De Proportione Motus*.

[1] Translation by T. J. McCormack (Open Court, 1893), p. x.

[2] E. Mach, *The principles of physical optics* (New York, 1925), p. 4.

[3] *Die Geschichte der Physik*, Part 2 (Braunschweig, 1884), p. 126.

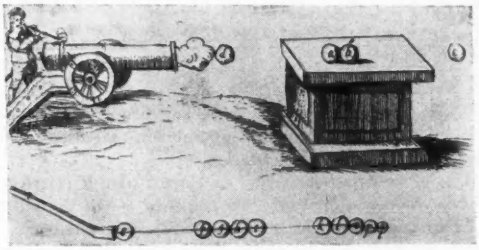

PLATE 3. Illustration from Marcus Marci's *De Proportione Motus.*

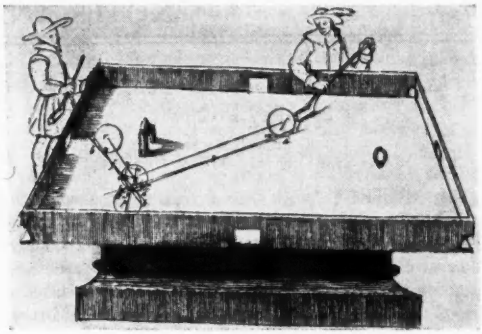

PLATE 4. Illustration from Marcus Marci's *De Proportione Motus.*

garding the motion of falling bodies and hence of force and acceleration as did GALILEO, he was the first to make substantial progress with the difficult problem of impact, a problem that GALILEO touched on without success and that DESCARTES completely muffed. Thus he clearly states both that an elastic body making direct impact with a second body of the same size at rest will itself remain at rest after the impact while communicating its entire motion to the second body and that two equal elastic bodies moving in opposite directions with the same speeds will after impact simply reverse their motions, that is, exchange velocities. He also had a very considerable knowledge concerning pendulum motion, centrifugal force, and the composition of motions, and he restated GALILEO's theorem that the time of descent down all chords which start from the top of a vertical circle is the same.

All this is cleverly summarized in the frontispiece to the *De Proportione Motus*. This charming engraving (reproduced as Plate 2) shows weights being dropped from a high tower, shots fired from a cannon impinging upon other shot, an early form of billiard table and a man batting a ball against a wall, as well as a man swinging from two ropes (pendulum motion) and sparks flying off tangentially from a grinding wheel (centrifugal force). The cannon-ball experiment and the billiard table are shown in greater detail in two other engravings that illustrate the text. These are reproduced here as Plates 3 and 4.

A great advance in science, though nothing could at first sight seem less poetical, inevitably results in a change both in the style and in the substance of poetry, as well as in the taste that judges it. A whole book might be written on the influence of Copernicus on poetic production, and another on poetry as modified by Darwin. "In Memoriam," for instance, though written before the "Origin of Species," is full of the thoughts which were soon to be clarified by that work, and could never have been written had not the "Vestiges of Creation" appeared shortly before: while, though Milton still hankered after the Ptolemaic cosmogony, "Paradise Lost" is in part the work of Galileo and Kepler. It is hard—if we may leap to a later date—to imagine the loss the literature of Germany and the world would have sustained if Goethe had not been a student of science. Faust is informed throughout by the new scientific spirit, alike in its doubts and in its certainties; the philosopher is the physicist of the early nineteenth century, and Mephistopheles is the darker aspect of the same philosophy.—E. E. KELLETT, *The whirligig of taste.*

NOTES AND DISCUSSION

A Mechanical Model for the Climbing Monkey Problem

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"A MONKEY hangs from a rope that passes over a frictionless pulley to a coconut that weighs just as much as the monkey. How can he get the coconut?" The answer of course is that if the monkey climbs the rope, the coconut will rise with him at the same rate on the other side of the pulley. Because this question always arouses interest in mechanics, a number of suggestions for mechanical models to illustrate the answer have been given.[1] Mention of one of the simplest, and in several ways the best model, seems to have been neglected, though the idea has undoubtedly occurred to many others.

The monkey can be represented by a toy called a yo-yo which will wind itself up and down a string. (See Fig. 1.) This string can then pass over a pulley to a suitable weight. The weight and wound-up yo-yo are released simultaneously just below the pulley, whereupon they will fall and rise together a number of times. The demonstration gains its effectiveness from the fact that the motion is repeated instead of stopping after one upward trip, as in most models. The pulley obviously should have little friction, so that the weight will stay as nearly opposite the yo-yo as possible.

If one wished, instead of using a commercial yo-yo one could construct a spool-like version that would be superior. It could be weighted to have a large moment of inertia, so as to slow the action. With a large moment of inertia and a relatively small axle, the disturbing jerk at the bottom of the travel is reduced because of the smaller linear velocity for a given travel. However, these suggestions should not be carried too far or the variations in tension, which give rise to the phenomenon, will be decreased until they become comparable in magnitude with disturbing effects such as friction.

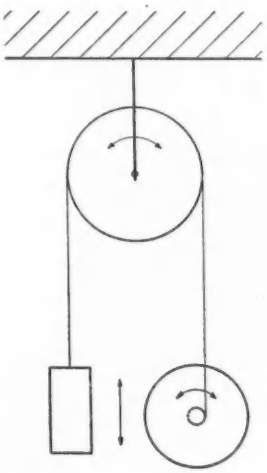

FIG. 1. Model for climbing monkey problem.

Use of light, strong string or thread with a relatively heavy yo-yo will minimize the tendency of the wound-up cord to unbalance the system. Finally, if a tendency to twist about the string should prove troublesome it can be corrected by using two strings (on opposite ends of a longer cross member) which pass over two pulleys and then both go to the counterweight.

[1] R. M. Sutton, ed., *Demonstration experiments in physics* (McGraw-Hill, 1938), p. 52.

Transverse-Wave Apparatus

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A COMMON method, usually ascribed to Professor P. G. Tait, of deriving the equation $v=(T/\rho)^{\frac{1}{2}}$ for the velocity of a transverse wave along a flexible string is to imagine the string to be running in a smooth tube. It is shown that the string will not press against the walls of the tube, whatever its curvature or shape, if the foregoing relation connecting the velocity v, the tension T and the mass per unit length ρ is satisfied. The tube is then not needed to maintain the string in a given form and may be considered removed. The situation is that of a stationary wave form in the moving string, or the string may be considered at rest and the wave form traveling along it with a velocity v.

Students are often surprised that the velocity does not depend on the wave form. It is not easy to perform an experiment such as that described, but the essential features of the situation can be demonstrated with an endless belt running over two pulleys.[1]

One-pulley and two-pulley systems were tried with cords of various materials—leather, rope, string, chain, empty-rubber tubing and sand-filled rubber tubing; of these, the sand-filled rubber tubing in a two-pulley system proved to be the most satisfactory. The pulleys were placed one above the other and separated by a distance of approximately 8 ft. (Fig. 1). On the whole, placement of the pulleys in this manner gave better reflected wave forms and required less clearance between slack and taut sides of the belt than when the pulleys were at the same level. Also, the apparatus is rugged and easy to construct and transport.

The lower pulley is driven by a variable speed, direct current motor which is continuously controlled by a field rheostat. The motor should be sufficiently large that slight load variations do not appreciably alter the speed. The position of the upper pulley—a small bicycle wheel of 13-in. diameter—was made adjustable so that the tension in the "string" could be changed.

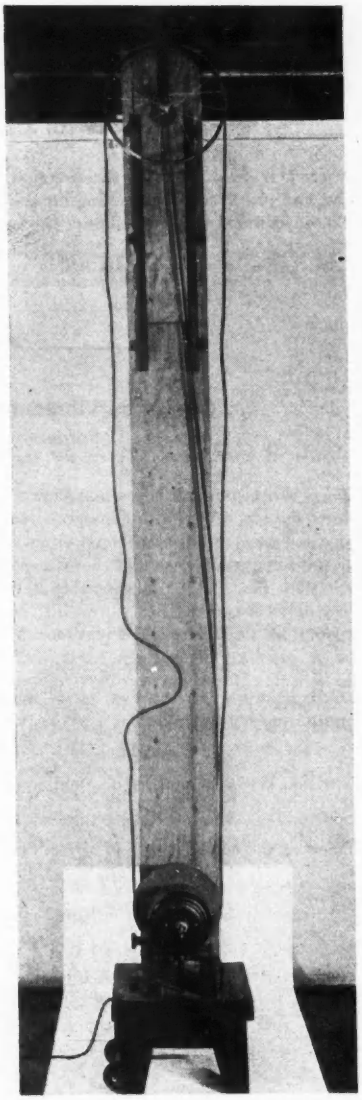

FIG. 1. Transverse wave apparatus: $v=46$ ft/sec; exposure time, 10^{-4} sec.

The continuous belt was made of a 12-ft length of gum-rubber tubing, of outside diameter $\frac{3}{4}$ in. and wall thickness $\frac{1}{8}$ in. The mass per unit length was increased by filling the tubing with fine sand. Ideal, but very difficult to make, is a belt that is uniform throughout. A simple method of splicing has been used successfully. After the sand has been poured into the tubing and packed (by stroking and shaking), one end of the tube is spread open while the other end is forced into it. Three or four turns of fish line wrapped around this joint do keep these ends from pulling apart. The tube is left empty for $\frac{3}{4}$ in. at each end to allow for the splicing.

Rubber tubes of different sizes or dimensions may be used for belts, and then the dependence of the velocity on mass may be demonstrated. Quantitative measurements, accurate to within 2 percent, are easily obtained with the apparatus. With a clamp fastened to both sides of the tubing at some convenient point between the two pulleys, and the tubing removed from the lower pulley, weights may be added to return the clamp to the position occupied when the tubing is around both pulleys. Typical values obtained with this apparatus are: total mass of tubing, 371 g, total length of belt, 18 ft; tension, 1150 gwt; v, 45.7 ft/sec. Values obtained with a Strobolux were were $f=8$ rev/sec (upper pulley) and $v=45.4$ ft/sec.

The speed of the pulleys can be adjusted so that when the slack side of the belt is struck a sharp blow near the upper pulley, the wave form travels slowly downward. Various wave forms can be impressed on the belt, and the student can readily see that the speed is not altered.

The tension in the belt is slightly greater near the upper pulley than at the lower one; hence the speed of the wave decreases as it moves downward. It is not possible to make the velocity such that the wave form is stationary, because at this velocity the belt does not cling to the pulleys. This behavior is to be expected when one examines the condition assumed in deriving the equation for the velocity.

The wave form may require a few seconds to pass from the upper to the lower pulley, since its speed is the difference between that of the wave and the belt. When it arrives at the lower pulley, it is reflected and now travels upward with a speed equal to the sum of the velocities of the belt and wave. The return to the upper pulley is too quick for the eye to follow. A wave may be reflected several times before its energy is dissipated. To the eye it seems rather weird to have the wave reappear at the upper pulley after having traveled down the slack side of the belt and to see, on striking the belt near the lower pulley, a wave form produced at the upper pulley. One may strike the taut side near the top and have a wave appear at the bottom, or one may start a wave at the lower end of the taut side and watch it move slowly upward.

[1] A similar experiment is described in R. M. Sutton, ed., *Demonstration experiments in physics* (McGraw-Hill, 1938), p. 139, exp. S-29.

Classical Theory of Van der Waals Forces

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THE weak attractive forces between neutral molecules or atoms not connected by ordinary valence bonds have long been known by the name of Van der Waals forces. Such forces may arise because of the interaction between: (i) permanent dipoles, (ii) permanent dipoles and induced dipoles, or (iii) fluctuating dipoles. The cohesive forces in water are an example of forces of the first type. The solubility of helium and the rare gases in water is an example of the second type. Finally, the forces holding together liquid or gaseous helium, neon, argon, and krypton

are an example of the third type. In this note, only the forces arising from the interaction between permanent dipoles and induced dipoles or from the interaction between fluctuating dipoles will be calculated. The formulas to be derived will be essentially the same as those obtained by the perturbation method in quantum mechanics. However, the method used here is direct and easily understood and is not ordinarily presented.[1]

Consider a polarizable isotropic particle in an electric field. The electric moment of the dipole induced in the particle will be in the direction of and proportional to the electric field intensity; that is,

$$\mathbf{p}=\alpha\mathbf{E},$$

where $\mathbf{p}$ is the induced dipole moment, α the polarizability, and $\mathbf{E}$ the electric field intensity. The potential energy of the dipole is the negative of the work done in producing it, or

$$U=-\int E\,dp=-\tfrac{1}{2}\alpha E^2.$$

Now, in the case of Van der Waals forces, the field intensity E is produced either by permanent dipoles or by fluctuating dipoles. In either case, the components of electric field intensity at a point $P(r,\theta)$ due to a single given dipole of moment p_0 are given by the equations

$$E_r=\frac{2p_0}{r^3}\cos\theta,\quad E_\theta=\frac{p_0}{r^3}\sin\theta,$$

where r is the distance from the center of the given dipole to P, and θ is the angle between r and the axis of the given dipole which, for convenience, is taken as the z axis. Thus,

$$E^2=E_r^2+E_\theta^2=\frac{p_0^2}{r^6}(3\cos^2\theta+1).$$

Therefore,

$$E^2=\frac{p_0^2}{r^6}\left(3\frac{z^2}{r^2}+1\right),$$

where $z=r\cos\theta$. Hence, the potential energy of an induced dipole at P is

$$U=-\tfrac{1}{2}\alpha\left(\frac{p_0^2}{r^6}\right)\left(3\frac{z^2}{r^2}+1\right).$$

In order to compute the average value of U, it is necessary to calculate the mean-square value of z. Now, the induced dipole and the given dipole are always coplanar, since the induced dipole will always lie on a line of force which, in turn, defines a plane. In order to find the mean-square value of z, consider $P(r,\theta)$, the center of the induced dipole, to move along a great circle of constant radius r, one of whose diameters is coincident with the z axis. The equation of the path is

$$z^2+\rho^2=r^2,$$

where ρ is the perpendicular distance of P from the axis of the dipole (the z axis). The mean-square value of z can now be easily computed; it is

$$(z^2)_{Av}=\frac{1}{2r}\int_{-r}^{r}z^2\,d\rho=\tfrac{2}{3}r^2.$$

Therefore, the average energy of the induced dipole is

$$\bar{U}=-3\alpha(p_0^2)_{Av}/2r^6,$$

where $(p_0^2)_{Av}$ is the mean-square dipole moment. This formula is the same as the one derived in quantum mechanics.[2]

The Van der Waals force acting on one of the induced dipoles due to the given dipole is

$$\mathbf{F}=-\nabla\bar{U}=\tfrac{3}{2}\alpha\nabla\left(\frac{(p_0^2)_{Av}}{r^6}\right)=-\frac{9\alpha(p_0^2)_{Av}}{r^7}\mathbf{r}_1,$$

where $\mathbf{r}_1$ is a unit vector in the direction of r. This value of the Van der Waals force acting on one induced dipole is almost identical with that obtained by quantum theory.

[1] However, the general procedure is suggested in J. C. Slater, *Introduction to chemical physics* (McGraw-Hill, 1939), p. 366.
[2] See, for example, Slater and Frank, *Introduction to theoretical physics* (McGraw-Hill, 1933), p. 553.

On Forced Vibrations

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IT is the purpose of this note to show that the integration of the second-order, inhomogeneous, linear differential equation that describes a forced vibration can be reduced to the integration of a fourth-order homogeneous linear equation. The solution is, with this method, obtained in a very direct way.

Consider the differential equation

$$\ddot{x}+\omega_0^2x=f\sin\omega_1t,\tag{1}$$

which defines a forced vibration of the quantity x. Differentiating both members of Eq. (1) twice, we obtain

$$x^{IV}+\omega_0^2\ddot{x}=-\omega_1^2f\sin\omega_1t=-\omega_1^2(\ddot{x}+\omega_0^2x).$$

Equation (1) is therefore equivalent to the equation

$$x^{IV}+(\omega_0^2+\omega_1^2)\ddot{x}+\omega_0^2\omega_1^2x=0.\tag{2}$$

If $\omega_1\neq\omega_0$, the general solution of Eq. (2) is

$$x=A_0e^{i\omega_0t}+B_0e^{-i\omega_0t}+A_1e^{i\omega_1t}+B_1e^{-i\omega_1t}.\tag{3}$$

Substituting this expression in Eq. (1), we obtain

$$\begin{aligned}&-\omega_0^2(A_0e^{i\omega_0t}+B_0e^{-i\omega_0t})-\omega_1^2(A_1e^{i\omega_1t}+B_1e^{-i\omega_1t})\\&\quad+\omega_0^2(A_0e^{i\omega_0t}+B_0e^{-i\omega_0t})+\omega_0^2(A_1e^{i\omega_1t}+B_1e^{-i\omega_1t})\\&\qquad=f\sin\omega_1t=(f/2i)(e^{i\omega_1t}-e^{-i\omega_1t}).\end{aligned}$$

This identity is satisfied, for any values of A_0, B_0, if

$$(\omega_0^2-\omega_1^2)A_1=f/2i$$

and

$$(\omega_0^2-\omega_1^2)B_1=-f/2i.$$

From these conditions we obtain

$$A_1e^{i\omega_1t}+B_1e^{-i\omega_1t}=[f/(\omega_0^2-\omega_1^2)]\sin\omega_1t.\tag{4}$$

The values of A_0, B_0 are determined from the initial conditions $x(0)=x_0$, $\dot{x}(0)=v_0$. Taking these into account, and using Eq. (4), we can rewrite Eq. (3) in the form

$$x=a\sin(\omega_0t+\varphi_0)+[f/(\omega_0^2-\omega_1^2)]\sin\omega_1t,$$

where

$$a\equiv[x_0^2+(v_0/\omega_0)^2]^{\frac{1}{2}},\tag{5}$$

and

$$\varphi_0\equiv\tan^{-1}(\omega_0x_0/v_0).\tag{5'}$$

If $\omega_1=\omega_0=\omega$, the general solution of Eq. (2) is

$$x=(A_0+A_1t)e^{i\omega t}+(B_0+B_1t)e^{-i\omega t}. \quad (6)$$

Substituting this expression in Eq. (1), we obtain

$$-\omega^2(A_0+A_1t)e^{i\omega t}-\omega^2(B_0+B_1t)e^{-i\omega t}+2i\omega A_1e^{i\omega t}$$
$$-2i\omega B_1e^{-i\omega t}+\omega^2(A_0+A_1t)e^{i\omega t}+\omega^2(B_0+B_1t)e^{-i\omega t}$$
$$=(f/2i)(e^{i\omega t}-e^{-i\omega t}),$$

which is again satisfied, for any values of A_0, B_0, if

$$2i\omega A_1=2i\omega B_1=f/2i. \quad (7)$$

Determining A_0, B_0 as before in terms of the initial conditions, and using Eqs. (5), (5′) and (7), we see that Eq. (6) becomes

$$x=a\sin(\omega_0t+\varphi_0)-(f/2\omega)t\cos\omega t,$$

which describes a phenomenon of resonance.

The foregoing procedure can be applied, with obvious generalizations, to the integration of the more general equation,

$$\ddot{x}+\alpha\dot{x}+\omega_0^2x=f\sin(\omega_1t+\varphi_1).$$

NECROLOGY

Alva W. Smith, 1885-1948

IN the death of ALVA W. SMITH, Professor of Physics at The Ohio State University, on January 21, 1948, the profession of physics has lost a wise counselor and one of its most gifted teachers, one who was primarily interested in the development of the scientific and human resources of physics students.

PROFESSOR SMITH was born at Fayette, Ohio, on August 26, 1885. Both his undergraduate and his graduate work, except for one summer quarter at the University of Chicago, was completed at The Ohio State University, which awarded him the A.B. degree in 1912, the A.M. in 1914 and the Ph.D. in 1921. Except for one year spent at the Western Electric Company and one summer at the National Bureau of Standards, his entire professional career was devoted to teaching and research at The Ohio State University. He was appointed instructor in the Department of Physics in 1915, promoted to assistant professor in 1921; to associate professor in 1930 and to professor in 1940. He was a fellow of the American Association for the Advancement of Science, and a member of the American Physical Society, the American Association of Physics Teachers, Sigma Xi and Phi Beta Kappa.

As a member of the University Faculty Council and also of the Executive Committee of the College of Arts and Sciences, he contributed, with his usual clarity of thought and vision, to the solution of many university and college problems. Within the Department of Physics he had an important voice in the determination of department policies, methods of instruction, content of courses and curricular changes. At the time of his death he was chairman of the committee concerned with plans for the new physical laboratory. In this capacity he gave careful consideration to laboratory and classroom needs of students of general physics. As a faculty advisor to scores of students he assisted them in attaining their proper objectives and shaped their courses of study so that they were prepared for scientific careers.

PROFESSOR SMITH taught physics as a living and growing science with human interests and vital social and industrial implications. His high devotion to this challenging adventure was illustrated in many ways. He never met a class, even the most elementary, without having planned in advance a definite procedure and the goals at which he aimed. He took pains to illustrate his demonstration lectures with interesting experiments, and he possessed unusual ability in devising significant demonstration and laboratory experiments to illustrate fundamental physical principles. With exceptional patience, tolerance and clarity of logic he undertook to make the subject matter of physics intimate, concrete and vital—a point of departure for a new intellectual life. He often realized what seemed to others an impossibility—enthusiasm for the subject without a sacrifice of sound judgment and independent thinking. Although he always upheld high standards of rigorous thinking and sound teaching, he was never criticized by his students. His teaching was too intimate and friendly for criticisms.

His interests in teaching extended beyond his own department. The students of electrical

engineering came in intimate contact with him through his courses on electricity and magnetism and his laboratory on electrical measurements. He understood their needs and interests and made a maximum effort to satisfy them. He cooperated with many of them in the preparation of their theses and on special research projects. For many years he enjoyed the reputation of being their most beloved instructor. For one quarter he served as exchange professor in the Department of Electrical Engineering. He was so well liked by the students in the class that, at the completion of the course, a special meeting was called by the students at which they presented him with a gift as an expression of their appreciation of his interest and teaching.

Although it may be correctly said that PROFESSOR SMITH's primary interest was in teaching, he recognized that students of physics must be trained to be creative and that research is the means to that end. Thus, recognizing research as the highest form of teaching, he participated effectively in the research program of the Department of Physics. His special interest was in electrical and magnetic measurements and in supersonics. Alone, or in cooperation with his students, he published a number of scientific papers in these fields. They represent inadequately his contribution to physics. Many of his more significant ideas cannot be identified. They are embodied in the advice and suggestions that he so freely gave to students struggling with some research problem, most frequently in some field other than physics.

One of the most unusual and outstanding things about PROFESSOR SMITH's relation to his students was the extraordinary care he took to see that the students working under his direction, whether in his classes or in other departments, never failed to receive the help and attention which he could give them. He measured his success largely in terms of the later achievements of his students, and he took great pains to keep in actual contact with them, by correspondence or otherwise, after they left the University. There was thus formed a series of lasting ties which will long survive.

PROFESSOR SMITH was a man of tireless energy, always cheerful and helpful, pursuing his scientific and personal interests without haste and without rest. He had an unusual gift for friendship both for his students and for his colleagues, never wearying in acts of kindness and simple courtesy which endeared him to all his associates. The loyalty and consideration, courage and good humor with which he carried on until the day of his death will always be affectionately remembered by his friends, students and colleagues. He will have a living memorial in the lives and careers of students who had the good fortune to work with him or under his supervision and to profit from his clear-sighted counsel and unselfish interest.

ALPHEUS W. SMITH

New Members of the Association

The following persons have been made *members* or *junior members* (*J*) of the American Association of Physics Teachers since the publication of the preceding list [*Am. J. Physics* 16, 190 (1948)].

Ackerman, Eugene (*J*), A 10 Van Hise Ave., Madison 5, Wis.
Akerib, Richard (*J*), University of Colorado, Boulder, Colo.
Alexander, Thos. L., Riverside Military Academy, Gainesville, Ga.
Allmon, Edward C., University of Georgia, Athens, Ga.
Anderson, John E. (*J*), 921 Lane K, Spencer Park, Hastings, Neb.
Bayless, Carleton A. (*J*), Apt. 2-E, 2101 Cutting Blvd., Richmond, Calif.
Birtley, Willard B. (*J*), 418 Windcrest, State College, Pa.
Bornstein, Lawrence A., 2361 Valentine Ave., New York 57, N. Y.
Briggs, Edgar V., 5221 Otsego St., Duluth, Minn.
Brown, Walter N., Jr., 226 S. Gill St., State College, Pa.
Bruner, Joe J., College of Aeronautical Engineering, Tulsa, Okla.
Bullen, Thomas G., Iona College, New Rochelle, N. Y.
Cabanas, Willie O., Box 1114, Mayaguez, Puerto Rico.
Calfee, Robert F., University of Denver, Denver, Colo.
Canter, Herbert M. (*J*), 3301 Shady Ave., Pittsburgh 17, Pa.
Chimino, David F. (*J*), Box 328, Atlantic Mine, Mich.
Clements, John H., South Dakota State College, Brookings, S. D.
Cleveland, Ernest L., 131 West Park Ave., State College, Pa.
Coffman, Moody L. (*J*), Box 736, Woodrow Wilson Center, Norman, Okla.
Cohen, Leslie, 2820 Auchentoroly Terrace, Baltimore 17, Md.
Dank, Milton (*J*), 4246 Parkside Ave., Philadelphia 4, Pa.
Derenthal, Richard J. (*J*), 2043 Bayard Ave., St. Paul 5, Minn.
Deshotels, Warren J., University of Iowa, Iowa City, Iowa.
Dolan, James J., 75 N. Cleveland Ave., St. Paul 5, Minn.
Doss, Thomas T. (*J*), Austin College, Sherman, Tex.
Dougherty, Rev. Cletus, Delbarton School, Morristown, N. J.
DuBois, James G. E. (*J*), 11272 Nebraska Ave., West Los Angeles 25, Calif.
Dvorak, Robert F., Route 2, Hinsdale, Ill.
Fisher, Russell A., Northwestern University, Evanston, Ill.
Geisert, Antone A., 5829 N. Mobile Ave., Chicago 30, Ill.
Gelinas, Robert W. (*J*), 3206 Howard Park Ave., Baltimore 7, Md.
Gibson, Robert W., William Penn College, Oskaloosa, Iowa.
Goldstein, Jack S. (*J*), 524 W. Brooks, Norman, Okla.
Gordon, William L. (*J*), Barracks 1-H, New Concord, Ohio.
Grimsal, Edward G. (*J*), 408 Garfield Ave., Kalamazoo, Mich.
Guiley, George M., 618 Buena Vista, Ashland, Ohio.
Hatch, Albert J., Physical Science Laboratory, State College, N. M.
Hemenway, Curtis L., Rutgers University, New Brunswick, N. J.
Herman, Otto W. (*J*), Murray State Teachers College, Murray, Ky.
Hernandez, Jose M., Box 163, Mayaguez, Puerto Rico.
Hildebrand, Bernard, Rensselaer Polytechnic Institute, Troy, N. Y.
Hornbeck, George A., 8621 Georgia Ave., Silver Spring, Md.
Hough, William S. (*J*), 1108 S. Westnedge Ave., Kalamazoo 41, Mich.
Ildstad, Reidar T., P. O. Box 151, Pittsburgh 5, Pa.
Immaculata, Sister Mary, St. Joseph's College for Women, Brooklyn 5, N. Y.
Jewell, Paul V., University of Maryland, Princess Ann, Md.
Kimberling, Delmar H., Mohawk College, Utica 5, N. Y.
Kime, D. O. Western Union College, Le Mars, Iowa.
Lagarias, John S., 450 S. Atlantic Ave., Pittsburgh, Pa.
Lange, Karl O., "Lancrest," RR 5, Lexington, Ky.
Levine, Emanuel, 66 Beacon Ave., Jersey City 6, N. J.
Levinstein, Henry, Syracuse University, Syracuse, N. Y.
Loyd, Coleman M., West Virginia Institute of Technology, Montgomery, W. Va.
McCarthy, Francis W., 15 Orchard St., Jamaica Plain 30, Mass.
McDonald, Raymond E., College of the Holy Cross, Worcester 3, Mass.
McGrago, Rev. George C., Providence College, Providence, R. I.
McIntosh, Charles R., College of St. Thomas, St. Paul, Minn.
Madigan, John A., College of St. Thomas, St. Paul 1, Minn.

DIGEST OF PERIODICAL LITERATURE

Connecting Many Wires to One Terminal

To fasten one or more wires to one terminal, select a washer that is a loose fit on the terminal screw and hook the wires through its hole (Fig. 1); then thread the washer over the screw and secure it with a nut. When some wires are

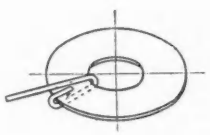

FIG. 1.

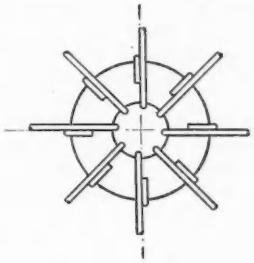

FIG. 2.

thin and others thick, it is best to use separate washers for each, with an additional washer between them. Usually eight or ten wires can be attached to one washer (Fig. 2). The author has frequently used this method and has never known a wire to come loose. H. HARTRIDGE, *J. Sci. Instruments* **25**, 16 (1948).

Transparent Clips on Scales

On instruments such as closed-end manometers it is often inconvenient to have portions of the tube obscured by opaque clips used to clamp the tube to its support. Transparent clips may be made from strips cut from $\frac{1}{16}$-in. Perspex sheet, warmed over a flame and pressed to the

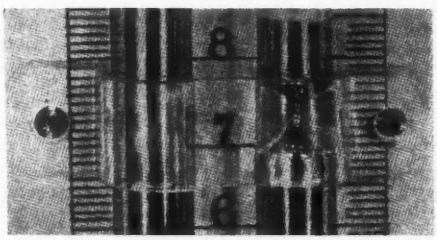

FIG. 1. Example of transparent clip; the meniscus and scale are clearly visible.

required shape over the actual manometer tube (Fig. 1).—L. ELSON, *J. Sci. Instruments* **25**, 16 (1948).

Relativity in the General Course

The subject of relativity is neglected by almost all textbooks for the beginner. It should be included in the basic course, for it may be presented simply and logically, without use of higher mathematics; it has a strong appeal to student interest; it presents a new idea of far-reaching significance; it is a controversial topic, and as such stimulates thinking. It may follow mechanics, or it may be part of a survey of modern developments. If the Michelson-Morley experiment is made the starting point, it should follow the study of interference in optics. The Lorentz transformations should be derived, and used to set up the equations for mass, momentum, force and energy. The mass-energy equation, in particular, should be discussed. For the average college freshman class, three to five hours is sufficient for an adequate presentation. K. RIESS, *Sch. Sci. Math.* **46**, 63–67 (1946).

Wave Mechanics for Undergraduates

Although the fundamentally important principles of wave mechanics are generally believed to be far too difficult for introduction into elementary courses, a major simplification can be accomplished by a careful coordination of three teaching aids: (i) emphasis on the nodes of matter-wave patterns, rather than on the resulting electron distribution functions; (ii) interpretation of the simpler wave functions by diagrams colored to show the sign and intensity of the function; (iii) employment of similarly colored *mathematical curves* in dynamic models which are so simple that students can construct some themselves.

Most recent popular books on physical science make some mention of the quantum theory and wave mechanics, in recognition of their tremendous implications. Imaginative and mechanically minded students deserve a better substitute for the obsolete Bohr-Sommerfeld atom model than such a discouraging remark as "the new structures cannot be visualized." The pictures suggested by atomic wave patterns are unequalled in their intricate symmetry, striking beauty and perfect harmony of finite discreteness with infinite continuity.

In introductory interpretations, a certain amount of simplification is justified; and, without sacrificing intellectual honesty, many of the disturbing vagaries and complications of wave mechanics in its present incomplete state can be avoided in a simplified approach. The elementary approach begins with a summary of the impressive accumulation of evidence leading to the unified theory. The growing awareness of the complexity of the atom some 75 years ago culminated with Balmer's study of the hydrogen spectrum, which is the beginning of modern atomic theory. This is followed with brief discussions of the Rutherford nuclear model; the Lewis-Langmuir model; the Bohr-Sommerfeld model, with the introduction of quantum numbers; and the Hund-Landé vector model. Then is presented the evidence leading to ideas concerning the particle nature of energy, the wave nature of matter, and the "atomic" nature of their interaction.

The electron's attendant matter wave is a statistical pattern of its behavior—a three-dimensional pattern that is described completely in terms of two direction angles and the radius. For atom-bound electrons the patterns are most easily described by the nodes, or regions of zero wave intensity. These nodes are surfaces, spherical, conical or

planar. There is a simple correspondence of the nodes with the three Bohr-Sommerfeld quantum numbers.

The periodic system of the elements follows naturally and inevitably from the wave patterns; it is a purely mathematical and physical result, based on genuinely basic principles, without the necessity for considering any chemical properties. Simple mechanical models can be made to illustrate by analogy the structure of these wave patterns.

The details of the method of solving the wave equation or of its derivation are not necessary, but the solutions themselves are surprisingly simple and can be easily understood. W. J. WISWESSER, "The periodic system and atomic structure," *J. Chem. Ed.* **22**, 314–322, 370–379, 418–426 (1945).

Kundt Tube-Sonometer Experiment

A steel wire (violin E string) is mounted between the supports of a Kundt tube, one end being attached to a screw for changing the tensile force and the other to a spring balance for measuring it. The metal rod of the Kundt tube apparatus is set into longitudinal vibration, and the tension and length of the steel wire are varied until resonance is obtained. Two bridges serve to determine the vibrating length of the wire. Resonance is signaled by the displacement of small paper riders on the string. In this way the frequency of vibration of the Kundt tube rod is known when that of the wire is known. The latter is found by resonance with several standard tuning forks. The advantage of this experiment over the usual form with the Kundt tube is that the velocity of sound in air need not be assumed. P. WRIGHT, *Sch. Sci. Rev.* **29**, 199–201 (1948).

Vibrating-String Demonstration

A brass wire is used as the string on a simple sonometer, and the ends of the wire are connected to the 6.3-v secondary winding of a small filament transformer. The primary winding is connected to the input of an audio amplifier. The output of the amplifier feeds a loudspeaker and a cathode-ray oscilloscope.

A small horseshoe magnet, preferably of Alnico, is placed over the mid-point of the string, and the latter is set into vibration. An alternating current is thus induced in the string, and its presence is made evident on the loudspeaker and the oscilloscope. If the magnet is placed at the antinode of another of the harmonics, the presence of that harmonic is shown. The intensity is higher if two magnets are used—say at one-fourth and three-fourths the length of the string for the second harmonic—due attention being paid to polarity. It is possible to pick up in this way the first 15 harmonics. The effect of changing the length or the tension of the string can also be shown. R. C. GRUBBS, *Sch. Sci. and Math.* **48**, 199–201 (1948).

Vacuum Siphons

A siphon works quite readily in an evacuated vessel, and the height to which the liquid may be raised is not limited by the height of the barometer.

A glass tube is sealed through the upper end of a cylindrical bulb, the lower end of which is closed. A few centimeters above the seal the tube is bent through 180°, and the other end, which projects some distance below the bottom of the aforementioned bulb, is sealed through the top of a second, similar bulb, which is thus some distance below the first bulb. The glass tube should reach nearly to the bottom of the upper bulb, but should project only a short way into the lower bulb, and the end in the latter bulb should be somewhat constricted. The two bulbs are joined by a second tube, having a side connection with a stopcock, by which the apparatus may be partly filled with liquid and then evacuated.

Enough liquid is introduced so that by tipping the apparatus the siphon tube is filled and its reservoir is nearly filled. The apparatus is then evacuated, the stopcock is closed and the apparatus set vertical. The siphon at once runs until the reservoir is empty. The liquid may be mercury, dibutyl phthalate or water, boiled to exclude air. If water is used, the tube should be sealed off while the water is boiling; it then works very well. Before filling, the apparatus must be carefully cleaned.

A similar apparatus with a height of some 80 cm between the upper bulb and the bend of the siphon tube and filled with mercury shows that the siphon will work at a height exceeding that of the barometer. This apparatus should be mounted on a board for convenience in handling. M. C. NOKES, *Sch. Sci. Rev.* **29**, 233–4 (1948).

Check List of Periodical Literature

Science legislation: National Science Foundation bills. E. Johnson, *Sch. Sci. and Math.* **48**, 143, 233, 312 (1948). A compilation of digests of bills introduced in Congress and periodical articles dealing with the proposed National Science Foundation.

Some ethical implications of science. A. C. Ivy, *Sch. Sci. and Math.* **48**, 206–215 (1948).

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Control and beneficial use of atomic energy. S. K. Allison, *Sch. Sci. and Math.* **48**, 259–268 (1948).

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Use of punched card techniques in the coding of inorganic compounds. J. C. Bailar, Jr., K. F. Heumann and E. J. Seiferle, *J. Chem. Ed.* **25**, 142–143 (1948).